PCT

WORLD INTELLECTUAL PROPERTY ORGANIZATION
International Bureau

INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(51) International Patent Classification 6 : G11B 11/00

A1

(11) International Publication Number: WO 98/48418

(43) International Publication Date: 29 October 1998 (29.10.98)

(21) International Application Number: PCT/US98/06651

(22) International Filing Date: 2 April 1998 (02.04.98)

(30) Priority Data:

08/844,167	18 April 1997 (18.04.97)	US
09/019,225	4 February 1998 (04.02.98)	US

(63) Related by Continuation (CON) or Continuation-in-Part (CIP) to Earlier Applications

US	08/844,167 (CIP)
Filed on	18 April 1997 (18.04.97)
US	09/019,225 (CIP)
Filed on	4 February 1998 (04.02.98)

(71) Applicants *(for all designated States except US)*: READ-RITE CORPORATION [US/US]; 345 Los Coches Street, Milpitas, CA 95035 (US). QUINTA CORPORATION [US/US]; 1870 Lundy Avenue, San Jose, CA 95131-1826 (US).

(72) Inventors; and

(75) Inventors/Applicants *(for US only)*: BISCHOFF, Peter, G. [US/US]; 24009 Oak Knoll Circle, Los Altos Hills, CA 94022 (US). MCDANIEL, Terry [US/US]; 16755 Feliz Court, Morgan Hill, CA 95037 (US). WANG, Yugang [CN/US]; 1687 Tahoe Drive, Milpitas, CA 95035-7028 (US).

(74) Agent: KASSATLY, Samuel, A.; 6819 Trinidad Drive, San Jose, CA 95120 (US).

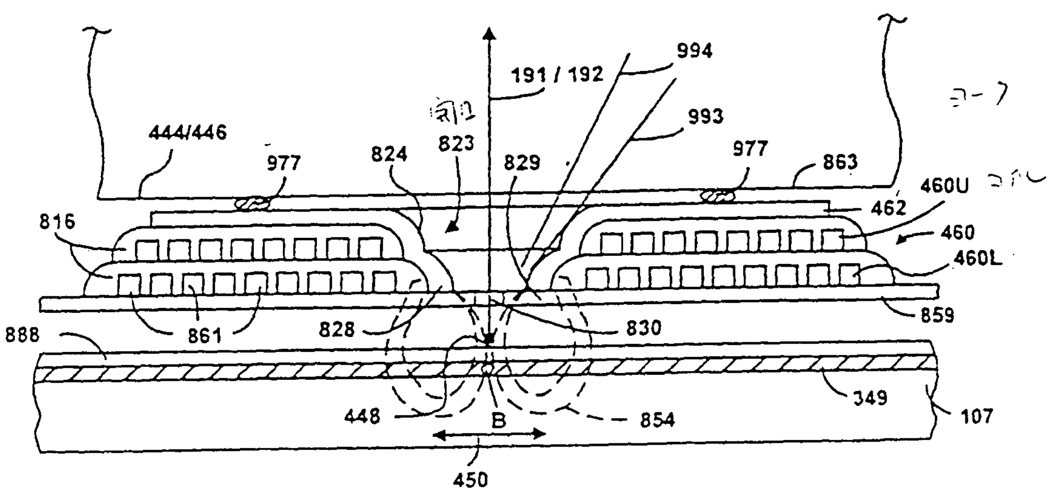
(81) Designated States: DE, GB, JP, KR, SG, US.

Published

With international search report.

With amended claims.

(54) Title: THIN-FILM ELECTRO-MAGNETIC COIL DESIGN FOR USE IN A FLYING MAGNETO-OPTICAL HEAD



(57) Abstract

A thin-film micro coil (460U, 460L) is used in a flying magneto-optical head (106) includes a coiled conductor (861) that cooperates with a yoke (462) to permit an optimal magnetic flux density to be formed at a target point on the surface of, or within a storage medium. The yoke is formed of three sections: an upper section (863), an intermediate section (816) and a tip that defines an optical opening (823) and has its underside substantially flush with, or recessed relative to the underside of the undercoat layer for increasing the density of the magnetic field at a target distance from the coil. The yoke tip underside is defined by an inner edge that delineates the optical opening and that is formed of two semi-circular sections and two linear sections tangential to the semi-circular sections. The yoke can optically include an outer section that extends over the peripheral side of the insulation layer and that further extends in an enlarged toe section.

FOR THE PURPOSES OF INFORMATION ONLY

Codes used to identify States party to the PCT on the front pages of pamphlets publishing international applications under the PCT.

AL	Albania	ES	Spain	LS	Lesotho	SI	Slovenia
AM	Armenia	FI	Finland	LT	Lithuania	SK	Slovakia
AT	Austria	FR	France	LU	Luxembourg	SN	Senegal
AU	Australia	GA	Gabon	LV	Latvia	SZ	Swaziland
AZ	Azerbaijan	GB	United Kingdom	MC	Monaco	TD	Chad
BA	Bosnia and Herzegovina	GE	Georgia	MD	Republic of Moldova	TG	Togo
BB	Barbados	GH	Ghana	MG	Madagascar	TJ	Tajikistan
BE	Belgium	GN	Guinea	MK	The former Yugoslav Republic of Macedonia	TM	Turkmenistan
BF	Burkina Faso	GR	Greece	ML	Mali	TR	Turkey
BG	Bulgaria	HU	Hungary	MN	Mongolia	TT	Trinidad and Tobago
BJ	Benin	IE	Ireland	MR	Mauritania	UA	Ukraine
BR	Brazil	IL	Israel	MW	Malawi	UG	Uganda
BY	Belarus	IS	Iceland	MX	Mexico	US	United States of America
CA	Canada	IT	Italy	NE	Niger	UZ	Uzbekistan
CF	Central African Republic	JP	Japan	NL	Netherlands	VN	Viet Nam
CG	Congo	KE	Kenya	NO	Norway	YU	Yugoslavia
CH	Switzerland	KG	Kyrgyzstan	NZ	New Zealand	ZW	Zimbabwe
CI	Côte d'Ivoire	KP	Democratic People's Republic of Korea	PL	Poland		
CM	Cameroon	KR	Republic of Korea	PT	Portugal		
CN	China	KZ	Kazakstan	RO	Romania		
CU	Cuba	LC	Saint Lucia	RU	Russian Federation		
CZ	Czech Republic	LI	Liechtenstein	SD	Sudan		
DE	Germany	LK	Sri Lanka	SE	Sweden		
DK	Denmark	LR	Liberia	SG	Singapore		
EE	Estonia						

THIN-FILM ELECTRO-MAGNETIC COIL DESIGN FOR USE IN A FLYING MAGNETO-OPTICAL HEAD

BACKGROUND OF THE INVENTION

This invention relates generally to optical and magneto-optical data storage systems, and in particular to a thin film electro-magnetic coil for use in flying magneto-optical heads.

A conventional magnetic storage system generally includes a magnetic head comprised of a slider and a magnetic read/write. The head is coupled to a rotary actuator magnet and a voice coil assembly by a suspension and an actuator arm, and is positioned over a spinning magnetic disk. In operation, lift forces are generated by aerodynamic interactions between the magnetic head and the spinning magnetic disk. The lift forces are opposed by equal and opposite spring forces applied by the suspension such that a predetermined flying height is maintained over a full radial stroke of the rotary actuator assembly above the surface of the spinning magnetic disk.

Flying head designs have been proposed for use with optical and magneto-optical (MO) storage technology. One motivation for using the magneto-optical technology stems from the availability of a higher areal density with magneto-optical storage disks than magnetic storage disks. However, despite the historically higher areal storage density available for use with magneto-optical disks drives, existing magneto-optical disk drive volumetric storage capacity has generally not kept pace with the volumetric storage capacity of magnetic disk drives.

One factor that limits the MO disk drives storage capacity is the coil that generates the necessary magnetic field for writing data on the MO disk. The magnetic field is applied to a spot of interest on the MO disk from the direction of the incident laser beam, or from the opposite direction. However, the magnetic coils used in these commercial magneto-optical heads are relatively large and heavy devices with bulky hand wound coils. These large magnetic coils generally have high inductance and low resonance frequencies leading to background noise

problems at higher data transfer rates.

The following patents provide examples of electro-magnetic coil designs for use in various applications, including data storage systems: U.S. Patent No. 4,890,178 to Ichibara; U.S. Patent No. 5,022,018 to Vogelgesang et al; U.S. Patent No. 5,072,324 to Lin et al.; U.S. Patent No. 5,105,408 to Lee et al.; U.S. Patent No. 5,124,961 to Yamaguchi et al.; U.S. Patent No. 5,197,050 to Murakami et al.; U.S. Patent No. 5,295,122 to Murakami et al.; U.S. Patent No. 5,307,328 to Jacobs et al.; U.S. Patent No. 5,331,496 to Wu et al.; U.S. Patent No. 5,370,766 to Desaigoudar et al.; U.S. Patent No. 5,544,131 to Albertini et al.; U.S. Patent No. 5,563,871 to Bargerhuff et al.; U.S. Patent No. 5,572,179 to Ito et al.; U.S. Patent No. 5,615,183 to Ishii; U.S. Patent No. 5,642,336 to Albertini et al; Japanese patent application No. 59-117180; Japanese patent application No. 06-325-426 A; Japanese patent application No.03-260-936 A; and Japanese patent application No.03-113-756 A.

What is needed, therefore, is an electro-magnetic coil that presents an improvement over conventional coils. The new coil should improve the disk access time, improve the areal storage density of storage media, and reduce the head weight and size.

SUMMARY OF THE INVENTION

One aspect of the present invention is to provide an electro-magnetic coil for attachment to a slider in a flying optical or magneto-optical head. The electro-magnetic coil has compact, low mass, and high field characteristics, and generates a large magnetic field intensity in the vertical direction. Another aspect of the electro-magnetic coil assembly resides in its relatively inexpensive mass production and assembly cost. The manufacturing process of the electro-magnetic coil assembly is compatible with proven wafer processing techniques, and provides highly efficient throughput for mass production.

The foregoing and other objects and features of the present invention are achieved by a thin-film electro-magnetic coil comprised of a coiled conductor that is covered by a yoke for providing a magnetic path to the magnetic field generated by the electro-magnetic coil. In one embodiment, the optical head includes: a reflective substrate or

mirror, an objective optic element, an optical fiber, and/or a quarter-wave plate. The reflective substrate may include steerable micro-machined optics positioned along the optical path of a read/write light (e.g. laser) beam so as to direct the light through the electro-magnetic coil to an optical storage media. The electro-magnetic coil is centered within an outer diameter of the objective optics, and includes a two-layer coiled conductor housed partly within the yoke and encapsulated within an insulation layer.

The coiled conductor can be formed of one or multiple layers, as well as one or more dielectric protective layers disposed between the conductive layers. The electro-magnetic coil and yoke are suitably dimensioned along a major axis to allow for an unobstructed optical path for steering of the light by the steerable mirror. The electro-magnetic coil, including the yoke, may have an elongated or circular geometry. The yoke includes a yoke tip that is suitably dimensioned to extend through an inner circumference of the electro-magnetic coil, so as to permit an optimal magnetic flux density to be formed at a predetermined target point on the surface of, or within an optical or magneto-optical storage media. In one embodiment the storage media is an optical storage media.

According to still another embodiment, the yoke is formed of three sections: an upper section, an intermediate section, and the tip. The yoke tip defines an optical opening and has its underside substantially flush with a protective undercoat layer for increasing the effective magnetic field density of the electro-magnetic coil. The tip underside is defined by an inner edge which delineates the optical opening, and which is formed of two semi-circular sections and two linear sections tangential to the semi-circular sections. According to yet another embodiment, the electro-magnetic coil further includes an additional turn formed within the undercoat layer in close proximity to the yoke tip, in order to further enhance the magnetic field density generated by the electro-magnetic coil.

BRIEF DESCRIPTION OF THE DRAWINGS

The features of the present invention and the manner of attaining them, will become apparent and the invention itself will be understood by reference to the following description and the accompanying drawings, wherein:

Fig. 1 is a schematic, top plan view of a magneto-optical (MO) data storage and retrieval system incorporating a thin-film electro-magnetic coil according to the present invention;

Fig. 2 is a schematic diagram of a laser-optics assembly forming part of the magneto-optical data storage and retrieval system of Fig. 1;

Fig. 3 is a schematic diagram of a head gimbal assembly (HGA) forming part of the magneto-optical data storage and retrieval system of Fig. 1. and illustrating an optical path comprised of an optical fiber and an optical switch;

Fig. 4A is a perspective view of a magneto-optical head forming part of the HGA of Fig. 3;

Fig. 4B is a cross-sectional view of the magneto-optical head of Fig. 4A, taken along line 4B;

Fig. 4C is an enlarged, cross-sectional view of the magneto-optical head of Fig. 4B, taken along line 4C;

Fig. 4D is a side elevational view of the magneto-optical head of Fig. 4A;

Fig. 4E is a front elevational view of the magneto-optical head of Fig. 4A;

Fig. 4F is a bottom plan view of a slider forming part of the magneto-optical head of Fig. 4A;

Fig. 5 is a side elevational view of a GRIN lens forming part of the magneto-optical head of Fig. 4A, further illustrating the optical path;

Fig. 6 is a top plan view of the HGA of Fig. 3. shown in motion over a magneto-optical storage medium such as a disk:

Fig. 7 is a schematic diagram illustrating data tracks that are gained by positioning the objective optics and electro-magnetic coil of the present invention at. or near a corner of the magneto-optical head;

Fig. 8 is a greatly enlarged, perspective, cross-sectional view of the electro-magnetic coil forming part of the magneto-optical head of Fig. 4A;

Fig. 9 is a cross-sectional, side elevational view of the electro-magnetic coil of Fig. 8, taken along line 9-9;

Fig. 10 is a top plan view of a coiled conductor forming part of the electro-magnetic coil of Figs. 8 and 9;

Fig. 11 is a cross-sectional, side elevational view of another embodiment of the electro-magnetic coil of Fig. 8, taken along line 9-9;

Fig. 12 is a cross-sectional, side elevational view of still another embodiment of the electro-magnetic coil of Fig. 8, taken along line 9-9;

Fig. 13 is a bottom plan view of a yoke tip forming part of the electro-magnetic coil of the present invention;

Fig. 14 is a bottom plan view of another yoke tip forming part of the electro-magnetic coil of the present invention;

Fig. 15A is a schematic, side elevational view of the data storage and retrieval system of the present invention;

Fig. 15B is a schematic, side elevational view of another data storage and retrieval system of the present invention;

Fig. 16 is a more detailed, fragmentary perspective view of a magneto-optical disk drive utilizing an electro-magnetic coil according to the present invention;

Fig. 17 is an enlarged, fragmentary, perspective view of the electro-magnetic coil of Fig. 16, shown secured to a slider and the optical assembly forming part of the disk drive of Fig. 16;

Fig. 18 is an enlarged top plan view of the electro-magnetic coil of Fig. 17;

Fig. 19 is an enlarged, perspective, cross-sectional view of the electro-magnetic coil of Fig. 18, along line 4-4;

Fig. 20 is an enlarged, cross-sectional view of the electro-magnetic coil of Fig. 19, shown bonded to the optical assembly;

Fig. 20A is an enlarged, cross-sectional view of another embodiment of the electro-magnetic coil of Fig. 19, shown bonded to the optical assembly;

Fig. 21 is a perspective view of the electro-magnetic coil of Figs. 18 and 19 illustrating two contact pads;

Fig. 22 is an enlarged, fragmentary, cross-sectional view of the electro-magnetic coil of Fig. 21 taken along line 7-7, and illustrating the entrance of a coiled conductor through a yoke forming part of the electro-magnetic coil of the present invention;

Fig. 23 is a perspective view of a two-layered coiled conductor forming part of the electro-magnetic coil of Figs. 18 and 19;

Fig. 24 is a side elevational view of the yoke forming part of the electro-magnetic coil of Figs. 18, 19 and 21, with the contact pads removed;

Fig. 25 is a cross-sectional view of an electro-magnetic coil according to another embodiment of the present invention, taken along line 10-10 in Fig. 25A;

Fig. 25A is a bottom plan view of the electro-magnetic coil of Fig. 25;

Fig. 25B is a side elevational view of the yoke forming part of the electro-magnetic coil of Fig. 25 with the contact pads removed;

Fig. 26 is an enlarged bottom plan view of a coil forming part of the electro-magnetic coil of Fig. 25, showing only a bottom or first layer and two contact pads;

Fig. 27 is a cross-sectional view of a coiled conductor forming part of the electro-magnetic coil of Fig. 26, taken along line 12 thereof, and showing a terminal end of one conductor layer overlaying a terminal end of another conductor layer;

Fig. 28 is an enlarged bottom plan view of a pole tip according to the present invention forming part of the electro-magnetic coil of Fig. 26;

Fig. 29 is an enlarged, cross-sectional view of an electro-magnetic coil according to still another embodiment of the present invention, taken along line 10-10 of Fig. 25A; and

Fig. 30 is an enlarged, cross-sectional view of an electro-magnetic coil according to yet another embodiment of the present invention, taken along line 10-10 of Fig. 25A.

Similar numerals refer to similar elements in the drawings. It should be understood that the sizes of the different components in the figures may not be in exact proportion, and are shown for visual clarity and for the purpose of explanation.

DETAILED DESCRIPTION

Fig. 1 illustrates a magneto-optical (MO) data storage and retrieval system (or disk drive) 100 according to the present invention. The system 100 includes, as an example only, a set of Winchester-type flying heads 106 that are adapted for use with a stack of storage media, such as a set of double-sided MO disks 107 (one flying head for each MO disk surface). Each flying head 106 (hereinafter also referred to as flying MO head) is coupled to a rotary actuator magnet and coil assembly 120 by a respective suspension 130 and actuator arm 105, so as to be positioned over a corresponding MO disk 107. In operation, the MO disks 107 are rotated by a spindle motor to generate aerodynamic lift forces between the flying MO heads 106, in order to maintain the MO heads 106 in a flying condition approximately 15 micro-inches above the upper and lower surfaces of the MO disks 107. The lift forces are opposed by equal and opposite spring forces applied by the suspensions 130. During non-operation, the flying MO heads 106 are maintained statically in a storage condition away from the MO disks 107.

System 100 further includes a laser-optics assembly 101, an optical switch 104, and a plurality of optical fibers 102, such as a set of single-mode PM (polarization maintaining) optical fibers. In an exemplary embodiment, each of the optical fibers 102 is (or selected optical fibers are) coupled through a respective actuator arm 105 and suspension 130 to a flying MO head 106. The flying MO heads 106 are used in a configuration that enables improved access to the high areal storage density capability of magneto-optical storage media, reduces the weight and size of the head, improves disk access time, requires fewer optical components, and increases the number of storage disks that may be operated within a given volume.

Fig. 2 further illustrates the laser-optics assembly 101, which includes a linearly polarized diode laser source 231 operating in a visible or near ultraviolet frequency region (other frequency ranges are possible) and emitting an optical power sufficient for reading data from, and writing reading data to (i.e., transducing data to and from) the MO disks 107. In a preferred embodiment, the linearly polarized laser source 231

is a distributed feed-back (DFB) laser source selected to operate within a range 635-685 nm; however, a laser or optical source of other frequencies can also be used.

The laser-optics assembly 101 further includes an optical isolator 297, a collimating optics 234, a low wavelength dispersion leaky beam splitter 232, and a coupling lens 233. The laser-optics assembly 101 directs (from the linearly polarized laser source 231) a linearly polarized outgoing laser beam 191 (also shown in Fig. 1) towards the optical switch 104. Laser-optics assembly 101 further includes a quarter-wave plate 238, a mirror or a reflective surface 235, and a polarizing beam splitter 232. A linearly polarized reflected laser beam 192 (shown in Fig. 1 and discussed below) is directed by the optical switch 104 towards the coupling lens 233, and is routed by the leaky beam splitter 232 towards a differential detector 240. The differential detector 240 includes the quarter-wave plate 238, the mirror 235, and the polarizing beam splitter 239. This type of differential detection scheme measures the optical power in two orthogonal polarization components of the reflected laser beam 192, with a differential signal being a sensitive measure of polarization rotation induced by the Kerr effect at the surface of one of the set of MO disks 107. After conversion by a set of photodiodes 236, the differential signal is processed by a differential amplifier 237 for output as signal 294. The present invention is not meant to be limited to the aforementioned arrangement of optical elements and sources of light, as other techniques for directing the outgoing laser beam 191 and for detecting the reflected laser beam 192 can be used.

Fig. 3 illustrates an exemplary optical path defined by one of the plurality of optical fibers 102 and the optical switch 104. In a preferred embodiment, an optical path is shown in Fig. 3 to include (or to be defined by) the optical switch 104, one or more of the set of single-mode PM optical fibers 102, and one or more of the set of flying MO heads 106. The optical switch 104 provides sufficient degrees of selectivity for selectively directing (or switching) the outgoing laser beam 191 towards a respective single-mode PM optical fiber 102. The outgoing laser beam 191 is further directed by the single-mode PM optical fiber 102 towards the flying MO head 106 and thereferom onto a surface recording layer 349 of a MO disk 107.

During the writing phase. the outgoing laser beam 191 is selectively routed by the optical switch 104 to the MO disk 107 so as to lower the coercivity of the recording layer 349 by heating a selected spot of interest 340 to approximately the Curie point of the recording layer 349. Preferably. the optical intensity of outgoing laser beam 191 is held constant, while a time varying vertical bias magnetic field is used to define a pattern of "up" or "down" magnetic domains perpendicular to the MO disk 107. This technique is known as magnetic field modulation (MFM). Alternatively, outgoing laser beam 191 may be modulated in synchronization with the time varying vertical bias magnetic field at the spot of interest 340, in order to better control domain wall locations and reduce domain edge jitter. Subsequently, as the selected spot of interest cools at the recording layer 349, information is encoded within the recording layer 349 of the respective spinning disk 107.

During the readout phase, the outgoing laser beam 191. having a lower intensity compared to writing. is selectively routed to the MO disk 107, such that at any given spot of interest 340, the Kerr effect causes, upon reflection of the outgoing laser beam 191 from the surface layer 349, the reflected laser beam 192 to have a rotated polarization of either clockwise or counter clockwise sense 363 that depends on the magnetic domain polarity at the spot of interest 340.

The aforementioned optical path is bi-directional in nature. Accordingly. the reflected laser beam 192 is received through the flying MO head 106 and enters the distal end of the single-mode PM optical fiber 102. The reflected laser beam 192 propagates along the single-mode PM optical fiber 102 to exit at its proximal end. and is selectively routed by the optical switch 104 for transmission to laser-optics assembly 101 for subsequent conversion to the signal 294.

Figs. 4A through 4F illustrate various views of the flying magneto-optical head 106. The flying MO head 106 generally includes a slider 444 having an air bearing surface 447, an optical assembly 500 and an electro-magnetic coil 460 having a yoke 462. The optical assembly 500 includes a quarter-wave plate 493. a reflective substrate or mirror 400, and an objective optics 446 mounted on (or at least partly within) the slider 444. It should be understood that the optical assembly 500 may include other optical

components and is not limited to the components listed herein.

The slider 444 is dimensioned to accommodate the physical size, numerical aperture (NA). and working distances between the objective optics 446, the single-mode PM optical fiber 102, and the reflective substrate 400. The reflective substrate 400 may include a reflective surface which is aligned so as to direct the outgoing laser beam 191 and 192 to and from the surface recording layer 349. Although, slider 444 may include industry standard "mini", "micro", "nano", or "pico" sliders, alternatively dimensioned sliders 444 may also be used (as determined by the dimensional constraints of the elements used with the flying MO head 106). Accordingly, in an exemplary embodiment, the slider 444 comprises a mini slider height (approximately 889 um) and a planar footprint area corresponding to that of a nano slider (approximately 1600 um x 2032 um).

The single-mode PM optical fiber 102 is coupled to the slider 444 along an axial cutout or channel 443, and the objective optics 446 is coupled to the slider 444 along a vertical cutout or channel 411. Although, in one embodiment the axial cutout 443 is located along a periphery or edge of the slider 444, and the vertical cutout 411 is located at a corner of the slider 444, the axial cutout 443 and the vertical cutout 411 may be located at other positions on the flying MO head 106, for example, between the periphery and a central axis or, alternatively, along the central axis itself. The positioning the optical fiber 102 and the objective optics 446 at other than along a central axis may affect the center of mass of the magneto-optical head 106 and, thus, its flying dynamics. Accordingly, the point of attachment of the MO head 106 to the suspension 130 (Fig. 3) may require adjustment to compensate for off-center changes in the center of mass of the MO head 106. The cutouts 443 and 411 may be designed as channels, v-grooves, or any other suitable means for coupling and aligning the single-mode optical fiber 102 and objective optics 446 to the MO head 106. In the preferred embodiment, the laser beams 191 and 192 traverse an optical path (to and from the surface recording layer 349 of the MO disk 107) that includes: the single-mode PM optical fiber 102, the reflective substrate 400, the quarter-wave plate 493, and the objective optics 446.

In a preferred embodiment, the single-mode PM optical fiber 102 and the objective optics 446 are positioned within their respective cutouts to achieve focus of the outgoing laser beam 191 within the spot of interest 340 as a focused optical spot 448. The single-mode PM optical fiber 102 and the objective optics 446 may be subsequently secured in place by using ultraviolet curing epoxy or similar adhesive. As compared to free space delivery of polarized laser light, the single-mode PM optical fiber 102 provides an accurate means of alignment and delivery of both the outgoing 191 laser beam to the reflective substrate 400. and of the reflected laser beam 192 from the reflective substrate 400 back to the laser-optics assembly 101.

The single-mode optical fiber 102 also provides a low mass and low profile optical path. The low mass of the single-mode optical fiber 102 provides a method of delivering light to the MO head 106 without interfering substantially with the operating characteristics of the actuator arm 105 and suspension 130 (Fig. 3). The low profile of the single-mode optical fiber 102 provides the ability to reduce the distance between the set of MO disks 107 without interfering with delivery of light or operation of the flying MO head 106.

The reflective substrate 400, quarter-wave plate 493, and objective optics 446 are of a preferably compact and low mass so as to fit within a physical volume approximating the general cubical volumetric dimensions of the slider 444 and, yet, sufficiently large to direct a full cross section of the outgoing and reflected laser beams 191 and 192, so that minimal power is lost and significant distortion and aberrations in the outgoing and reflected laser beams 191 and 192 are not introduced.

Fig. 5 illustrates an exemplary objective optics 446 that has a very small and low profile. The objective optics 446 includes a micro plano-convex GRIN lens (Graded Index) lens of a non-conventional design that provides a high effective NA, low size, and low mass single-element objective optics for use with the MO head 106. The GRIN lens (also referenced by the numeral 446) is made by polishing a conventional plano-plano GRIN rod lens to provide a convex surface.

The plano-convex GRIN lens 446 is cylindrical and includes at a bottom end 446B a plano surface and at an opposite end a convex surface with a radius of curvature of

approximately 190 um. As compared to a conventional GRIN lens, the cylindrical and planar portions of the GRIN lens 446 improve the ability to align the optical axis of the GRIN lens 446 relative to the optical path passing through the cutout 411 of the MO head 106. The use of a single optical element GRIN lens 446 eliminates the requirement for the alignment of multiple objective optic elements relative to each other.

In an exemplary embodiment, the GRIN lens 446 has a diameter approximately of 250 um (microns), and a length of approximately 329 um. An optical path length from a center point 419 of a reflective central mirror portion 420 of the reflective substrate 400 to the convex surface 461 of the GRIN lens 446 is approximately 435 um. The end 467 of the single-mode PM optical fiber 102 has a numerical aperture (NA) of approximately 0.15. and the distal end 467 of the single-mode PM optical fiber 102 is positioned approximately 450 um from the center point 419. The GRIN lens 446 has a gradient index function of sqrt(A) = 3.2, which provides an effective NA of approximately 0.67.

In an exemplary embodiment in which the laser-optics source 231 (Fig. 2) operates at a wavelength of approximately 650 nm, over the propagation angle of the outgoing laser beam 191, and as the reflective central mirror portion 420 rotates (or dither or vibrates), an optical spot 448 is preferably maintained with a full width at half-maximum intensity (FWHM) of approximately 0.54 um and with a RMS wavefront error of approximately $\lambda/20$ at a point approximately 25 um below the convex surface 461 of the GRIN lens 446. The GRIN lens objective optics 446, therefore, provides a small size and low mass high NA micro-objective element that is relatively easy to align within the MO head 106 during manufacture. While a specific embodiment of a plano-convex GRIN lens 446 has been described herein for illustration purpose, it will be appreciated that the GRIN lens 446 may comprise other geometries and the objective optics 446 may be formed of a different lens.

As is discussed above, the present invention uses objective optics 446 that are manufactured to very small dimensions. The optical and geometrical properties of the objective optics 446 permit a low profile and small diameter electro-magnetic coil 460 with a yoke 462 to be mounted on a bottom surface or air bearing surface

447 of the MO head 106 or, alternatively, on or near the surface of the objective optics 446, without affecting the aerodynamic flying performance of the MO head 106.

In a preferred embodiment, the reflective substrate 400 includes a steerable micro-machined mirror assembly comprised of a small (for instance less than 300 um square) reflective central mirror portion 420 (illustrated in Fig. 4A by dashed lines representative of the reflective central mirror portion on a side of the steerable micro-machined mirror assembly 400 opposite to that which is visible). The small size and mass of the steerable micro-machined mirror 400 contributes to the ability to design the MO head 106 with a low mass and a low profile. As used in the magneto-optical storage and retrieval system 100, fine tracking and short seeks to a series of nearby tracks may be performed by rotating the reflective central mirror portion 420 about a rotation axis so that the propagation angle of the outgoing laser beam 191 is changed before transmission to the objective optics 446.

The reflective central mirror portion 420 is rotated by applying a differential voltage to a set of drive electrodes 404/405 (Fig. 4B). The differential voltage on the drive electrodes 404/405 creates an electrostatic force that rotates the reflective central mirror portion 420 about a set of axial hinges 410, and enables the focused optical spot 448 to be moved in the radial direction of the MO disk 107. As an example, a rotation of approximately +/- 2 degrees of the reflective central mirror portion 420 is used for movement of the focused optical spot 448 in an approximately radial direction 450 of the MO disk 107 (equivalent to approximately +/- 4 tracks) for storage and retrieval of information, track following, and seeks from one data track to another data track. In other embodiments, other ranges of rotation of the reflective central mirror portion 420 are possible.

Coarse tracking may be maintained by adjusting a current to the rotary actuator magnet and coil assembly 120 (Fig. 1). The track following signals used to follow a particular track of the MO disk 107 may be derived using available combined coarse and fine tracking servo techniques. For example, a sampled sector servo format may be used to define tracks. The servo format may include either

embossed pits stamped into the MO disk 107 or magnetic domain orientations that are read similar to data marks. If embossed pits are used, an adder output circuit may be used in combination with the differential output circuit 237.

A conventional multiple platter Winchester magnetic disk drive may use a set of respective suspensions and actuator arms that move in tandem as one integral unit. Because each flying magnetic head of such an integral unit is fixed relative to another flying magnetic head, during track following of a particular magnetic disk surface simultaneous track following of another magnetic disk surface is not possible. In contrast, according to another embodiment of the present invention, and irrespective of the movement of the set of actuator arms 105 and the set of suspensions 130, the set of steerable micro-machined mirror assemblies 400 of the present invention may be used to operate independently and thus permit track following and seeks so as to read and/or write information using more than one MO disk (107) surface at any given time. Independent track following and seeks using a set of concurrently operating steerable micro-machined assemblies 400 would preferably require a set of separate respective read channel and fine track electronics and mirror driving electronics. As the latter embodiment could also preferably require the use of separate laser-optics assemblies 101, an optical switch 104 for switching between each of the separate optical paths might not necessarily be required.

Fig. 6 shows a magneto-optical head 106 in motion over the MO disk 107. In the preferred embodiment, the excursion of the optical spot 448 formed by the GRIN lens objective optics 446 over the surface recording layer 349 of the MO disk 107 is limited at the outer radius by a requirement that the flying MO head 106 maintain a stable aerodynamic flying height, and at the inner radius by mechanical constraints of the MO data storage and retrieval system 100 that limit movement of the actuator arm 105. Accordingly, in an exemplary embodiment, a maximum usable area of the surface recording layer 349 that the objective optics 446 may access, comprises a minimum inner radius r_i that is approximately 26.093 mm and a maximum outer radius r_o that is approximately 63.680 mm.

As an example, the MO disk 107 comprises 1406.5 data tracks/mm (e.g., a track

pitch of 0.711 um), and the flying MO head 106 is oriented over the MO disk 107 at the maximal inner excursion with a skew angle of approximately -13.53 degrees and at the maximal outer excursion with a skew angle of approximately 17.72 degrees (relative to tangential lines drawn at the radial data tracks located at the intersection point of the optical spot formed by the objective optics 446 and the minimum inner and maximum outer radii of the surface recording layer 349, respectively). The areal density over all the MO disk 107 radii is maximized using "zone recording" techniques to achieve an exemplary local area density of approximately 3.6 Gb per square inch. A maximum user data rate at the outer radius of the MO disk 107 includes at least 120 Mbits/sec (at a rotation rate of approximately 4500 RPM). Those skilled in the art will recognize that the user data rate R_D may be calculated using the relationship $R_D = (v) \times (D_L)$, where v is the disk velocity, and D_L is the linear bit density of the MO disk 107. The disk velocity v_0 at the outer radius of the MO disk 107 may be calculated using the relationship $v_0 = r_0\omega = (63.680\ \text{mm}) \times (2\pi\ \text{rad/rev}) \times (4500\ \text{rev/60sec}) = 30.008\ \text{m/s}$. Accordingly, the linear bit density D_L required to sustain the desired maximum user data rate at the outer radius may be calculated using the relationship $D_L = R_D / v_0 = (120\ \text{Mbits/sec}) / (30.008\text{m/s}) = 3998.9\ \text{bits/mm}$.

Fig. 7 illustrates the data tracks that are gained by positioning the objective optics 446 and electro-magnetic coil 460 at a corner of the magneto-optical head 106. The use of objective optics 446 along a central axis and/or inward from a periphery of a flying MO head 106 would result in data tracks at the outer radius of the MO disk 107 that may not be accessed. In the present embodiment, the GRIN lens objective optics 446 and the magnetic coil 460 (shown in Fig. 3) are located in proximity to, or at a periphery or side 485 of the slider 444 (as compared to objective optics 446 located inward from the side 485 and along a central axis of the flying MO head 106). the radial data tracks that may be accessed at the outer excursion of the flying MO head 106 is offset by approximately an equal number of radial data tracks that are inaccessible at the inner excursion of the flying MO head 106. The present invention makes use of the increased recording capacity of the data tracks at the outer radii as compared to the recording capacity of the data tracks at the inner radii. As a result, by positioning the

objective optics 446 and coil 460 offset from the central axis, the present invention increases the amount of data that may be written and read using the MO disk 107.

The increase in data accessible from the surface recording layer 349 of the MO disk 107 may be illustrated by comparing a position of the objective optics 446 and the coil 460 at a corner 487 of the MO head 106 to an objective optics 446 and a coil positioned along at point E, along the central axis X-X of the slider 444. This comparison is illustrated by a perpendicular distance between a tangential line drawn at a radial data track located at the optical spot formed by the objective optics 446 and a tangential line drawn at a radial data track located under point E. In the exemplary embodiment, the objective optics 446 and the electro-magnetic coil 460 are placed at a distance of approximately 0.0265 inch off-center from the central axis at, or in proximity to the corner 487 of the slider 444. At the maximal outer excursion of the slider 444, the perpendicular distance between the tangential lines (F and G) may be calculated as d_o = (0.0265 in) x (cos 17.72 degrees) = 0.02525 in = 641.165 um, and at the maximum inner excursion between the tangential lines (H and I) as d_i = (0.0265 in.) x (cos 13.53 degrees) = 0.025765 in = 654.42 um. Accordingly, compared to point E, the placement of the objective optics 446 and magnetic coil 460 at the corner of the flying MO head 106 results in a gain of approximately 902 data tracks at the maximal outer excursion of the flying MO head 106 (e.g., 641.165 um / 0.711 um/track), and a loss of approximately 921 tracks at the maximal inner excursion of the flying MO head 106 (e.g., 654.42 um / 0.711 um/track). In the exemplary embodiment, the data gained with the maximal outer excursion of the flying MO head 106 may be calculated using the relationship C_O = (902 tracks) x (D_L) x (2π) x (r_o'), where r_o' is a mean radius of the recording tracks gained (calculated as r_o - (0.5) x (641.165 um) = 63.3594 mm), and the data lost with the maximal inner excursion of the MO head 106 may be calculated from the relationship C_I = (921 tracks) x (D_L) x (2π) x (r_i'), where r_i' is a mean radius of the recording tracks lost (calculated as r_i - (0.5) x (654.42 um) = 26.4202 mm). Accordingly, C_O = 1.43595Gb = 179.493MB, and C_I = .061139Gb = 76.423MB. Compared to objective optics positioned at point E on the flying MO head 106, the present exemplary embodiment provides a net gain of approximately 103.070

Megabytes that may be read and written from the MO disk 107. Thus, compared to an optics 446 located along a central axis and inward from the periphery of an MO head (e.g., in proximity to point E), the placement of the objective optics 446 and the electro-magnetic coil 460 at, or in proximity to the peripheral side 485 of the flying MO head 106 provides an increase in the amount of data that may be read and written by the magneto-optical (MO) data storage and retrieval system 100. Although, the objective optics 446 has been described as being located along or in proximity to the peripheral side 487 of the slider 444, other positions of the objective optics 446 and electro-magnetic coil 460 may also provide improved data access.

Figs. 8 and 9 illustrate a magnetic coil in two representative cutaway views. In a preferred embodiment, the electro-magnetic coil 460 is a planar micro-coil that includes a conductor 861, which is coiled and housed at least partly within a yoke (or permeable flux guide) 462, and encapsulated within an insulation layer 816. In a preferred embodiment, the insulation layer 816 includes a suitable dielectric material, such as a photo-resist material. Although, in the preferred embodiment, the electro-magnetic coil 460 and yoke 462 may be formed on a suitable dielectric protective layer 859, it is understood that use of the electro-magnetic coil assembly of the present invention without the protective layer 859 is also possible. The protective layer 859 preferably includes an aperture 830 formed sufficiently wide for ensuring passage of the outgoing 191 and reflected 192 laser beams (Fig. 1) through a central passage 823 defined by a sloped section 824 of the yoke 462.

The sloped section 824 of the yoke 462 extends through a plane defined by at least one layer of the conductor 861 towards the central passage 823, terminating at the protective layer 859. In another embodiment, the electro-magnetic coil 460 and yoke 462 may be partly encapsulated within an overcoat (not shown) for added protection and insulation.

In a preferred embodiment, the yoke 462 guides the magnetic field created by the electro-magnetic coil 460 towards the layer 349 of the MO disk 107. The yoke 462 is made of a ferromagnetic material having a permeability of approximately 2000, for example, a nickel iron alloy (NiFe), and the yoke ranges in thickness from

approximately 4 um to approximately 6 um. The yoke tip 828 terminates at the upper surface of the protective layer 859 to preferably generate a magnetic field at, or in proximity to the target point B within the surface 349 layer of the MO disk 107. Fig. 9 illustrates the magnetic field lines 854 in dashed lines.

As further illustrated in Fig. 4c, the electro-magnetic coil 460 is mounted horizontally near the air-bearing surface 447 of the slider 444 at, or in proximity to the lower surface of the objective optics 446, and is centered with respect to an optical axis A-A of the objective optics 446. The conductor 861 may be made of suitable material such as copper, and is coiled to comprise between approximately 15 to 40 turns, and preferably, 21 turns.

In a preferred embodiment the electro-magnetic coil 460 includes an upper layer 460U and a lower layer 460L that are spaced apart in a vertical direction by approximately 6 um. In other embodiments fewer or greater numbers of layers, vertical spacings other than 6 um, as well as fewer or greater numbers of turns are possible. In an exemplary embodiment, a cross-sectional area of the conductor 861 may vary between approximately 2 um and 7 um. In a more specific embodiment, a cross-sectional geometry of the conductor 861 includes a height of approximately 3 um and a width of approximately 2 um. It should be understood that other cross-sectional geometries for the conductor 861 are possible, for example, circular or square cross-sections.

In a preferred embodiment, the electro-magnetic coil 460, including the coiled conductor 861, and the yoke 462 have a generally elongated geometry. More specifically the electro-magnetic coil 460 (hereinafter also referred to as elongated magnetic coil) including the coiled conductor 861 and the yoke 462 have a generally elliptical geometry. The outermost dimension of the conductors 861 along the major axis of the elongated magnetic coil 460 is less than approximately 150 microns and along the minor axis less than approximately 120 microns, and the innermost dimension of the conductor 861 along the major axis of the elongated magnetic coil 460 is less than approximately 50 microns and along the minor axis less than approximately 40 microns. An innermost dimension of the yoke 462 along the major

axis of the elongated magnetic coil 460 is less than approximately 25 microns and along the minor axis less than approximately 20 microns.

Compared to a circular magnetic coil that includes inner and outer dimensions that are equivalent to the inner and outer dimensions of the elongated magnetic coil 460 along the major axis, the elongated magnetic coil 460 provides an advantage in z-axis magnetic field generation efficiency and self-inductance that is better optimized with respect to the required function of moving the optical spot 448 in the disk radial direction 450 by means of the range of motion of the reflective central mirror portion 420 (Fig. 4a) during fine tracking and short seeks to adjacent tracks of the MO disk 107. The elongated magnetic coil 460 geometry provides a denser magnetic field at the surface of the MO disk 107 than would be possible with a circular coil. In the preferred embodiment, the use of the elongated magnetic coil 460 and its corresponding yoke 462 is expected to enhance the magnetic field by a factor of approximately two. The low profile and low mass of the elongated magnetic coil 460 minimize interference with the aerodynamic flying qualities of the MO head 106 such that the MO head 106 and, therefore, the elongated magnetic coil 460 and its associated yoke 462 may be positioned close to the MO disk 107. The small diameter of the elongated magnetic coil 460 and yoke 462 provides a further benefit, in that, small data marks may be recorded.

An exemplary-cross-section of the elongated magnetic coil 460 is illustrated in Fig. 9. The sloped section 824 of the yoke 462 at an inner diameter is shown in the plane of a major axis direction (x-axis) 993 of the elongated magnetic coil 460. The geometry of the sloped section 824 is a function of the optical path design as defined by the passage of the outgoing laser beam 191 through the central passage 823 during rotation of the reflective central mirror portion 420 (Fig. 4). A different geometry for the sloped section 824, which is referenced by the numeral 994, applies in the plane of the minor axis. In the preferred embodiment, even though the outermost diameter of the objective optics 446 is larger than the outermost diameter of the elongated magnetic coil 460. the elongated magnetic coil 460 including the yoke 462 do not interfere with the optical passage of light to and

from the MO disk 107.

The elongated and miniaturized design of the coil 460 can enable the head 106 to access more outer data tracks (that are located at, or close to the outer radius of the disk 107) than with a circularly shaped coil, depending on the orientation of the elongated coil 460. For example, the minor (or major) axis of the coil 460 can be substantially tangential to the outer periphery of the disk 107. Alternatively, the minor (or major) axis of the coil 460 can be oriented at an angle (for instance, approximately +45 degrees to -45 degrees) relative to the outer periphery of the disk 107.

In addition, the miniaturized size of the coil 460 relative to the size of the lens 446 also helps in optimizing the number of accessible outer tracks. Since the coil (460) major (or minor) axis (if the coil 460 were elongated), or the coil diameter (if the coil were circular) can be made smaller than the major or minor axis, or the diameter of the lens 446, the accessibility of the outer data tracks is not affected by the coil size, but rather by the lens size.

Although the elongated magnetic coil 460 and yoke 462 have been described to include an elliptical geometry, this geometry may be generalized to other situations in which alterations to the geometry of the elongated magnetic coil 460 and yoke 462 are made to accommodate a range of motion of an optical beam within the central passage 823, while also maintaining minimum spacing between the turns of the conductor 861 with the associated yoke 462 and the application point of a maximum magnetic field B. Accordingly, the geometries of other elongated magnetic coils 460, including yoke 462, and conductor 862 are within the scope of the invention; for example, oval, rectangular, etc. In another embodiment in which the reflective central mirror portion 420 is fixed, an elongated magnetic coil 460 including its associated yoke 462 with a circular geometry would be beneficial in generating a desired magnetic field at point B.

The vertical or z-axis (Fig. 8) geometry of the yoke sloped section 824 further assists in the generation of an optimal magnetic field. The upper surface 863 of the yoke 462 and the elongated magnetic coil 460 is secured to the objective optics 446

by available techniques, such as adhesive 977. In another embodiment, the elongated magnetic coil 460 and the yoke 462 may be adhesively secured to the bottom surface 487 of the slider 444, and/or the objective optics 446. Fig. 8 shows two pads 825 and 827 that extend from the yoke 462 onto the protective layer 859 for securing the coil 460 to the protective layer 859.

Fig. 10 illustrates the upper layer 460U of the coiled conductor 861. The conductor 861 extends in two contact pads 924, 926 for connection to an electrical or control circuit. The pads 924, 926 are preferably made of gold traces. With an applied current of less than 50mA, an input voltage of less than 12 volts, and a conductor (861) resistance of less than approximately 22 ohms, the elongated magnetic coil 460 exhibits a self inductance of less than approximately 200nH, and a capacitance of less than approximately 5pf. The magnetic field component in a plane perpendicular to the plane of the MO disk 107 (+/- 15 degrees) is reversible (80% +/- full strength) in a time of 4ns.

A separation distance between the tip 828 of the yoke 462 and the upper surface 888 of the MO disk 107 ranges between approximately 5um and 10um, such that a magnetic field of about 290 Gauss at point B is generated generally within the boundaries of the optical spot 448 formed by the outgoing laser beam 191. This compares favorably relative to conventional optical heads, which, because of their size required positioning at a distance farther away from the magnetic recording media (i.e., at other than the bottom surface of a head), and impose increased current requirements for generating a desired magnetic field density at the media surface.

In contrast, the present invention requires less current to generate an equivalent magnetic field density at the media surface. In addition, due to the self inductance limitations, the increased size and current requirements of the conventional magnetic coils are limited by the rate at which the magnetic field may be switched. In contrast, the reduction in size and current provided by the electro-magnetic coil 460 and its associated yoke 462 increases the rate at which information may be recorded. The bulky conventional coil designs also limit the number of heads that may be used within any given vertical spacing (z-height). Thus, for any given field strength, the use of the

yoke 462 in combination with the elongated coil 460 permits a smaller and less bulky flying magnetic head 106 geometry to be used.

Fig. 11 shows another electro-magnetic coil 1188 and a yoke 1189 that are generally similar to the electro-magnetic coil 460 and yoke 462 of Fig. 9 with the exception of the yoke 1189 configuration. While the yoke tip 828 in Fig. 9 extends towards. and terminates unto, or in very close proximity to the protective layer 859, the yoke tip 828 of the electro-magnetic coil 1188 is shown to be recessed relative to the protective layer 859, and separated therefrom by a tip 1190 of the insulation layer 816.

Fig. 12 illustrates another electro-magnetic coil 1253 and yoke 1254 according to the present invention. The electro-magnetic coil 1253 and yoke 1254 are generally similar to the electro-magnetic coils 460 and 1188 and yokes 462 and 1189, with the exception that the footprint of the pole tip 1255 of the yoke 1254 is increased. With further reference to Fig. 13, a bottom plan view of the footprint (or underside) of the yoke tip 828; as viewed from point B. is shown. The footprint of the yoke tip 828 is defined by two generally concentric edges: an outer edge 1312, and an inner edge 1313. The radial distance "d" between these two edges 1312 and 1313 determines the surface area of the footprint, and thus the magnetic flux density at point B. As further defined by Maxwell's equations, the vertical height or distance of the footprint of the yoke tip 828 relative to point B is a function of the footprint surface area, which, in turn, is a function of the radial distance "d". Although the edges 1312 and 1313 of yoke tip 828 are shown to be elongated. as discussed above, it should be clear that other shapes are within the scope of the invention.

Referring to Fig. 12 and Fig. 14. the footprint of the yoke tip 1255 is defined by two generally concentric edges: an outer edge 1312A. and an inner edge 1313A. The outer edge 1312A of the yoke 1254 generally corresponds to the outer edges 1312 of the yokes 462 and 1189. However, the inner edge 1313A of the yoke 1254 is closer to the central passage 830 than the inner edge 1313 of the yokes 462 and 1189. As a result, the radial distance "D" between the outer and inner edges 1312A and 1313A is greater than distance "d", and causes the magnetic flux density at point B to be higher than the magnetic flux density using the yokes 462 or 1188. In yet another embodiment the

inner edge 1313A substantially coincides with the edge 1314 of the central passage 830.

Figs. 15a and 15b illustrate two embodiments of the optical data storage and retrieval system 100, that are referenced by the numerals 1500 and 1600. In a preferred embodiment, the optical data storage and retrieval systems 1500 and 1600 are, or comprise a compact high-speed and high-capacity MO disk drive that includes an industry standard 5.25 inch half-height form factor (1.625 inch), at least six double-sided MO disks 107, and at least twelve flying MO heads 106. The flying MO heads 106 may be manufactured to include optical and magnetic elements that provide a very small mass and low profile high NA optical system so as to enable utilization of at least one double-sided MO disk 107 and preferably a plurality of double-sided MO disks 107 within a small form factor disk drive and; therefore, to comprise a higher areal and volumetric and storage capacity than is permitted in an equivalent volume of the prior art.

A spacing between each of the six MO disks 107 is approximately 0.182 inch, and the electro-magnetic coil 460 including the yoke 462 enable each side of the MO disk 107 to comprise at least 5 gigabytes of written data marks. The present invention should not, however, be limited by these specifications, as it is understood that in alternative embodiments other MO disk 107 data densities and other spacings between MO disks 107 are within the scope of the invention.

In an alternative embodiment, with a MO disk-to-disk spacing of approximately 0.182 inch, the half-height form factor MO system (or disk drive) 1600 may include a removable MO disk cartridge portion 1510 and two fixed MO disks 107. By providing the removable MO disk cartridge portion 1510, the fixed and removable combination permits external information to be efficiently delivered to the MO disk drive 1500 for subsequent transfer to the MO disks 107. The copied information may, subsequently, be recorded back onto the removable MO disk cartridge portion 1510 for distribution to other computer systems.

In addition, the removable MO disk cartridge portion 1510 allows for very convenient and high speed back-up storage of the MO disks 107. The fixed and

removable combination also permits storage of data files on the removable MO disk cartridge portion 1510 and system files and software applications on the MO spinning disks 107. In another alternative embodiment, a MO disk drive 1500 may include any number (including zero) of fixed MO disks 107 and/or any number of MO disks 107 within any number of removable MO disk cartridge portions 1510.

Although the present invention is described as being used in a MO disk drive 1500, 1600, the use of electro-magnetic coils as described herein may be practiced in many different optical disk drive embodiments, for example, read only optical drives, without use of a yoke, with other form factors, with other optical sources of light, with other types of optical fibers, and with other optical elements. Free space optical paths may also be used to deliver and receive laser light, for example, with a suitably aligned laser diode and detector mounted on the actuator arm or, alternatively, on the flying head itself. Additionally, the present invention does not necessarily require use of rotary actuator arms, for example, linear actuator arms may be used.

Fig. 16 illustrates a disk drive 2010 comprised of a head stack assembly 2012 and a stack of spaced apart optical or MO data storage disks or media 2014 that are rotatable about a common shaft 2015. The head stack assembly 2012 is rotatable about an actuator axis 2016 in the direction of the arrow C. The head stack assembly 2012 includes a number of actuator arms, only three of which 2018A, 2018B, 2018C are illustrated, which extend into spacings between the disks 2014.

The head stack assembly 2012 further includes an actuator block 2019 and a magnetic rotor 2020 attached to the block 2019 in a position diametrically opposite to the actuator arms 2018A, 2018B, 2018C. The rotor 2020 cooperates with a stator (not shown) for rotating in an arc about the actuator axis 2016. Energizing the coil of the rotor 2020 with a direct current in one polarity or the reverse polarity causes the head stack assembly 2012, including the actuator arms 2018A, 2018B, 2018C, to rotate about the actuator axis 2016 in a direction radial to the disks 2014.

A head gimbal assembly (HGA) 2028 is secured to each of the actuator arms, for instance 2018A. The HGA 2028 comprises a resilient load beam 2033 and a slider 2037 secured to the free end of the load beam 2033. The slider 2037 is also referred

to herein as a support element since it supports an optical assembly 2040 and / or an electro-magnetic coil 2044 (Figs. 4a, 4b, 17). The optical assembly 2040 is illustrated by a block drawn in dashed lines, and is secured to the HGA 2028 and in particular to the slider 2037 for providing the required optical reading and writing beams. An exemplary embodiment of the optical assembly 2040 is described above and referenced by the numeral 500.

The coil 2044 can be secured to the underside (or air bearing surface side) 2046 of the slider 2037, which is the surface facing the disk 2014, and to the optical assembly 2040. It should however be understood that the coil 2044 can be secured either to the slider 2037 or to the optical assembly 2040.

The details of the coil 2044 will now be described with reference to Figs. 18, 19, 20, 21, 22, 23 and 24. The coil 2044 comprises an electrical conductor 2050, and is formed by means of available thin-film wafer processing techniques. The coil 2044 has compact, low mass, and high field characteristics, and allows direct overwrite at a low flying height, with precise control of the focal plane of the optical assembly 2040. The coil 2044 does not interfere with vertical axis motion, thus ensuring that the focal plane of the optical assembly 2040 coincides generally with a MO layer 2053 (Fig. 20) of the disk 2014.

The overall mass of the coil 2044 may range between approximately 10 micrograms to 100 micrograms. The size compactness of the coil 2044 allows for an efficient design and results in a high magnetic field. The overall dimensions of the coil 2044 are significantly smaller than the slider underside 2046. In addition, since the coil 2044 is mounted directly on the slider 2037 and / or the optical assembly 2040, the flying height of the slider 2037 is not significantly affected by the presence of the coil 2044, thus ensuring the precise control of the flying height of the slider 2037 above the disk 2014 and the precise control of the vertical axis motion. As used herein, "vertical axis motion" refers to the focusing axis (or optical path) of an optical beam generated by the optical assembly 2040. In addition, the minimal thickness of the coil 2044 reduces the overall z-height (e.g. the vertical height or inter-disk spacing) of the head stack assembly 2012, thus enabling the disk drive 2010 to accommodate an optimal

number of disks 2014 in a predetermined space.

The coil 2044 further includes two bonding pads 2055, 2056 (Fig. 18) for providing electrical connection means to the conductor 2050. The bonding pads 2055, 2056 can be made of electroplated soft gold typically used in ultrasonic wire bonding applications. They are formed on a substrate 2052 using available deposition techniques, and are connected to the two terminal ends 2055A, 2056A (Fig. 23) of the conductor 2050. The conductor 2050 is firmly secured to the substrate 2052 by means of three contact pads 2061, 2062, 2063. It should be clear to a person of ordinary skills in the field that a different number of contact pads can alternatively be used.

A central optical passage 2070 is defined at the geometric center of the conductor 2050, for allowing an optical beam (e.g. a laser beam) 2072 (Fig. 20) to pass through. In one embodiment the central optical passage 2070 has a substantially circular contour and has its diameter vary between about 0.4 mil to about 1 mil, where one mil is equal to one thousandth of one inch. In another embodiment the central optical passage 2070 has an elliptically shaped contour (or geometry). In still another embodiment, the central optical passage 2070 has a square or rectangularly shaped contour, with its sides dimensions varying between about 0.4 mil to about 1 mil, with the longer side being generally oriented substantially perpendicularly to the track direction of the disk 2014 (i.e., radially relative to the disk 2014), for allowing the inter-track excursion of the optical beam 2072. Other dimensions and shapes can alternatively be selected provided they do not interfere with the free passage of the optical beam 2072. One such shape will be described later in connection with Figs. 26 and 28.

The following exemplary dimensions for the coil 2044 are included for illustration purpose and are not intended to limit the present invention. The length "L" of the coil 2044 ranges between approximately 30 mils and approximately 80 mils. The width "W" of the coil 2044 ranges between approximately 20 mils and approximately 40 mils.

The conductor 2050 is coiled, and is encapsulated, at least in part, within an insulation layer 2086. The insulation layer 2086 is covered by a yoke 2084 having a central optical opening 2070A that coincides and is aligned with the optical opening

2070 of the coil 50. The optical or laser beam 2072 passes through the central optical openings 2070. 2070A for impinging upon the disk 2014. According to this illustrative embodiment the optical openings 2070 and 2070A have a generally circular or elliptical shape; however, other shapes can alternatively be selected.

The conductor 2050 includes a plurality of multi-layered turns 2093 (Figs. 19, 20 and 23). for example 6 to 40 turns. with only two layers 2160, 2161 being shown. It should be understood that the conductor 2050 can be coiled into a different number of layers. The first or bottom layer 2160 is connected to the contact pad 2056 (Fig. 23), and is looped helically. inwardly. and terminates in an innermost end 2165 (Figs. 23 and 27). The second or upper layer 2161 starts with an innermost end 2167 (Figs. 23 and 27) that overlays the innermost end 2165 of the first layer 2160, in order to establish an electrical contact therewith, and to ensure the continuity of the electrical path formed by the conductor 2050. The second layer 2161 is coiled into a plurality of concentric helical turns 2093, similar to, and preferably in the same coiling direction as the first layer 2160, and is connected to the contact pad 2055 at its terminal end 2056A.

The conductor 2050 is made of a suitable electrically conductive material such as copper. While the conductor 2050 is illustrated as having a substantially uniform square cross section along its entire length. it should be understood that other appropriate shapes may be selected. The cross-sectional area of each turn 2093 varies between approximately 6 microns square and approximately 300 microns square, and preferably between approximately 12 microns square and approximately 20 microns square.

Generally, the turns 2093 are encapsulated within the protective insulation layer 2086, and are inter-spaced and separated by a distance varying between approximately 1 micron and approximately 12 microns, and preferably between approximately 1.5 microns and approximately 4 microns. The insulation layer 2086 is made of a suitable dielectric material, such as photoresist material.

The insulation layer 2086 defines a tip 2095 that extends beyond and underneath the tip 2097 of the yoke 2084. The tip 2095. as illustrated in the Figs. 19 and 20, is ring-shaped and concentric relative to the central optical passage 2070A and to another

optical opening 2100 in the substrate 2052. The shape of the optical opening 2100 is preferably similar to the contour to the optical passage 2070A. and has either a diameter or a side ranging between approximately 15 μm and approximately 40 μm. Preferably, the diameter or side of the optical opening 2100 ranges between approximately 13 μm and approximately 25 μm.

The tip 2095 positions the yoke tip 2097 relative to the disk 2014. such that a light spot 2101 formed by the laser beam 2072 on the surface of the disk 2014 coincides substantially with the maximum magnetic flux density (at point B) generated by the magnetic field on the MO layer 2053. This allows for optimal polarization of the disk 2014. While the inner surface 2105 of the yoke 2084 may taper inwardly, it should be understood that alternative configurations are also possible. For example, the inner surface 2105 may be substantially straight or stepped.

In the embodiment shown in Fig. 20 the height of the tip 2097 above the substrate 2052 is approximately equal to the height of the first layer 2160. It should however be understood that the height of the tip 2097 may vary in order to provide optimal optical and magnetic performance of the coil 2044. In the embodiment shown in Fig. 20A, the tip 2095 is eliminated, and the yoke tip 2097 extends to, or in proximity to in the substrate 2052. closer to the optical opening 2100.

The yoke 2084 is made of a suitable ferromagnetic high permeability material such as 81Ni :19Fe nickel iron alloy. The yoke 2084 has a substantially uniform thickness that ranges between approximately 1 micron and approximately 8 microns, and preferably between approximately 1 microns and approximately 4 microns. A distinctive feature of the coil 30 is that the yoke 2084 is formed on top of the insulation layer 2086 and the conductor 2050. but does not extend within the optical opening 2070 defined by the first layer 2160. The thickness of the yoke 2084 ranges between approximately 1 μm and approximately 6 μm. It should be clear that the quantities and dimensions mentioned herein are simply for purposes of illustration and that other values can be used instead.

In another embodiment. the yoke 2084 is covered by an overcoat layer for added protection and insulation. The overcoat layer provides an optical passage that

coincides with the optical openings 2070, 2070A for allowing the optical beam 2072 to pass through the coil 2044.

As illustrated in Fig. 20, the yoke 2084 of the coil 2044 is surface-mounted on the underside of the optical assembly 2040 (or the slider 2037) by means of available techniques, such as adhesive 2112.

Fig. 22 illustrates an opening 2115 formed in the yoke 2084 to allow the first layer 2160 to pass through the yoke 2084 for connection to the contact pad 2056. Another (or the same) opening is formed in the yoke 2084 to allow the second layer 2161 to pass through from connection to the contact pad 2055. While the terminal ends 2055A, 2056A and the corresponding contact pads 2055, 2056 are shown in this exemplary embodiment to be separated, it should be understood that in another embodiment they can be superimposed (or stacked) but electrically insulated from each other.

Another coil 2200 will now be described in connection with Figs. 25, 25A, 25B, 26, 27, 28. The coil 2200 includes a conductor 2232 which is encapsulated in part within an insulation layer 2256, which, in turn, is covered with a yoke 2255. The coil 2200 is deposited or made on an undercoat layer 2252 upon which the conductor 2232 is formed.

The conductor 2232 includes a plurality of multi-layered turns 2257, with only two layers 2260, 2261 are shown. The first or bottom layer 2260 is connected to a contact pad 2235 (Fig. 26) and is looped helically, inwardly, and terminates in an innermost turn 2264 (Figs. 25, 26) with a terminal end 2265 (Figs. 26, 27). The second or upper layer 2261 starts with a terminal end 2267 (Figs. 26, 27) of an innermost turn 2268 (Fig. 25). The innermost terminal end 2267 of the second layer 2261 overlays the innermost end 2265 (Fig. 27) of the first layer 2260, in order to establish an electrical contact therewith, and to ensure the continuity of the electrical path formed by the conductor 2232. The second layer 2261 is coiled into a plurality of concentric helical turns 2257 in the same coiling direction as the first layer 2260, and terminates in the contact pad 2336. The conductor 2232 has a similar composition and cross-sectional area as the conductor 2050.

With reference to Figs. 25 and 25A, the yoke 2255 has similar or equivalent

composition and cross-sectional area as the yoke 2084. In one embodiment an outermost edge 2258 (shown in dashed lines) of the yoke 2255 extends beyond an outermost edge 2259 of the conductor 2232, which, in this illustration is the outermost edge of the uppermost layer 2261, so that the yoke 2255 covers the conductor 2232.

The yoke 2255 is generally formed of three sections made using available thin film wafer technology, an upper section 2280, a sloping (or intermediate) section 2281, and a tip 2282 (also interchangeably referred to as toe 2282). The upper section 2280 is generally flat and disk shaped, and is formed on the insulation layer 2256, on top of the uppermost layer 2261 (in this example the second layer). The upper section 2280 extends integrally (or continuously) into the sloping section 2281 that covers an inner side of the insulation layer 2256. The sloping section 2281 has a generally conical shape. The sloping section 2281 extends continuously into the tip 2282. The tip 2282 is generally flat and ring (or cylindrically) shaped.

An important distinctive feature between the coil 2044 of Fig. 20 and the coil 2200 of Figs. 25, 25A, 28 is the close proximity of the yoke tip 2282 relative to the disk 2014. As a result, the size of the central optical opening 2070, 2300 is reduced, thereby further increasing the magnetic field density at the target point B. While the yoke tip 2097 of the coil 2044 (Fig. 20) is separated from the substrate 2052 by the insulation layer tip 2095, the underside 2314 (Figs. 25, 25B) of the yoke tip 2282 extends substantially to the level of the underside 2315 of the undercoat layer 2252, so that the yoke underside 2314 is substantially flush with the undercoat underside 2315. The coil 2200 includes an optical opening 2300 defined by the yoke tip 2282. Consequently, the yoke tip 2282 is positioned closer to the target point B, thus further enhancing the magnetic field density at the target point B.

The shape of the yoke 2255 will now be described with reference to Figs. 25, 25A and 28. In addition to the foregoing advantages presented by the yoke tip (2282) design, the yoke 2255 provides an optimal unobstructed travel trajectory for the optical beam 2072. The optical beam 2072 is focused on the target point B by means of a lens 2271 (or another optical device shown in a dashed line). The optical beam 2072 is conically shaped and defines an angle Θ with the Z-axis. The sloping section 2281 of the yoke 2255 is sloped at angle of approximately Θ relative to the Z-axis, so as to

accommodate the optical beam 2072. Fig. 25 illustrates a cross-sectional view of the coil 2200 along a minor axis (line 10-10 in Fig. 25A) of the yoke tip 2282, and shows the center line of the yoke sloping section 2281 to be substantially parallel to the optical beam 2072. The distance between the yoke sloping section 2281 and the optical beam 2072 ranges approximately 2 microns and approximately 15 microns, and preferably between approximately 3 microns and approximately 6 microns.

With particular reference to Fig. 28, the yoke tip 2282 is shaped to allow optimal cross-track excursion of the optical beam 2072. To this end, the underside 2314 of the yoke tip 2282 is defined by an inner edge 2321 and an outer edge 2322 that are generally concentric relative to each other. The inner edge 2321 delineates the optical opening 2300, and is formed of two arcuate sections 2325, 2327, and two linear sections 2329, 2331.

The arcuate sections 2325, 2327 are generally symmetrical relative to a minor axis m-m passing through a geometric center C of the inner edge 2321. In a preferred embodiment, the arcuate section 2325 is semi-circularly shaped with a radius R_B ranging between approximately 3 microns and approximately 15 microns, and preferably between approximately 5 microns and approximately 10 microns.

The linear sections 2329, 2331 are generally symmetrical relative to a major axis M-M passing through the geometric center C of the inner edge 2321. Each linear section 2329, 2331 is generally tangential to the arcuate sections 2325, 2327, and has its length ranging from approximately 3 microns and approximately 15 microns, and preferably between approximately 6 microns and approximately 8 microns.

The optical beam 2072 can travel a distance of ($2 R_A$) along the major axis M-M, where R_A ranges between approximately 6 microns and approximately 18 microns, and preferably between approximately 8 microns and approximately 12 microns. The present shape of the yoke tip 2282 provides a significant advantage over an elliptically shaped optical opening (shown in a dashed line in Fig. 28), since the present optical opening 2300 offers a wider passageway to the optical beam 2072, as denoted by the four shaded regions 2336, 2337, 2338, 2339. As a result, the optical beam 2072 can maintain a desired spot size and shape on the disk 2014.

In another preferred embodiment illustrated in Fig. 25, the yoke 2255 further includes an outer section 2262 that extends over the peripheral side of the insulation layer 2086, and that further extends in an enlarged toe section 2263.

The coil 2200 further includes an overcoat layer 2274 that overlays the yoke 2255 for added protection and insulation. The overcoat layer 2274 and the undercoat layer 2252 can be made of any suitable insulating material, for example alumina. An opening 2275 in the overcoat layer 2274 is co-aligned with the yoke 2255 to allow unobstructed passage of the optical beam 2072. The coil overcoat layer 2274 or the yoke 2255, is surface mounted on, or bonded to the slider underside 2046 (Fig. 17) and/or the optical assembly by means of available techniques, such as an adhesive.

The design objective of the coils 50 and 2232 can meet or exceed the following requirements:

- Coil current: less than, or equal to approximately 50 mA.
- Magnetic field: greater than, or equal to approximately 200 to 300 Oersteds.
- Coil Self-inductance: less than, or equal to approximately 60 to 100 nH.
- Capacitance: less than, or equal to approximately 3 to 5 pF.
- Resistance: less than, or equal to approximately 10 Ω.
- Input voltage: less than, or equal to approximately 7 V.

The foregoing values are provided for illustration purpose only, and the design criteria of the coils described herein can be varied with the desired applications.

Fig. 29 illustrates another coil 2400 according to the present invention. The coil 2400 is similar to the coil 2200 in construction and design; however, its conductor 2232 further includes an additional turn 2485 formed within the undercoat layer 2252. The turn 2485 is positioned in close proximity to the yoke tip 2282 and to the target point B, so as to further enhance the magnetic field density at the target point B. Additional turns 2485 (shown in a dashed line) can also be formed within undercoat layer 2252, as needed.

Fig. 30 illustrates another coil 2450 that is generally similar to any of the coils described herein, and in particular to the coils 2200 (Fig. 25) and 2400 (Fig. 29), wherein the yoke 2255 includes an outer section 2462 that extends over the peripheral

side of the insulation layer 2086, and further extends through at least part of the undercoat layer 2252. In another embodiment, the outer section 2462 extends in an enlarged toe section 463 which is substantially flush with the underside 2315 of the undercoat layer 2252.

Thus, while the present invention has been described herein with reference to particular embodiments thereof, a latitude of modification, various changes and substitutions are intended in the foregoing disclosure, and it will be appreciated that in some instances some features of the invention will be employed without a corresponding use of other features without departure from the scope of the invention as set forth.

What is claimed is:

1. A coil for mounting on a flying magneto-optical head including an optical element, to cooperate with the passage of an optical beam, the coil comprising:

a conductor; and

a yoke disposed intermediate the optical element and said conductor.

2. A coil according to claim 1, wherein said optical element includes a lens.

3. A coil according to claim 2, wherein the yoke is smaller than, or equal to said lens.

4. A coil according claim 1, wherein said conductor defines an elongated central passageway, and wherein said yoke defines an elongated passageway for the optical beam to pass through.

5. A coil according to any of claims 1, wherein said elongated passageways are generally co-axial, and wherein each of said elongated passageways defines a major axis for allowing the optical beam to be scanned therealong.

6. A coil according to any of claims 1, 2, 3, 4 or 5, wherein said yoke includes a sloped portion.

7. A coil assembly according to claim 6, wherein said sloped portion of said yoke extends at least in part within said elongated central passageway of said conductor.

8. A thin-film coil for use in a flying magneto-optical head comprising:

a multi-layered coiled conductor having an underside;

a yoke formed on said conductor for providing a magnetic path to a magnetic field generated by said conductor;

said yoke including a tip, and a central portion that defines an optical opening; and

said yoke tip terminating in substantial close proximity to said conductor underside.

9. A coil according to claim 8, further including an insulation layer that covers said conductor at least in part.

10. A coil according to any of claims 8 or 9, further including a protective layer on which said conductor is formed for protecting said conductor underside, wherein said protective layer includes a passageway that coincides substantially with said optical opening, and wherein said protective layer defines a tip that extends underneath said

yoke tip.

11. A coil according to any of claims 1, 2, 3, 4, 5, 8 or 9, wherein said conductor and said yoke are generally elliptically or circularly shaped.

12. A coil according to any of claims 1, 2, 3, 4, 5, 8 or 9, wherein said conductor includes two pads for connection to an electrical circuit.

13. A coil according to any of claims 1, 2, 3, 4, 5, 8 or 9, wherein said yoke is made of a ferromagnetic material having a permeability of approximately 2000.

14. A coil according to any of claims 1, 2, 3, 4, 5, 8 or 9, wherein said yoke has a thickness ranging from approximately 4 um to approximately 6 um.

15. A coil according to any of claims 1, 2, 3, 4, 5, 8 or 9, wherein said conductor includes two layers that are spaced apart along a vertical direction by approximately 6 um.

16. A coil according to any of claims 1, 2, 3, 4, 5, 8 or 9, wherein said conductor has a cross-sectional area ranging between approximately 2 um^2 and 7 um^2.

17. A thin-film coil for use in a flying magneto-optical head comprising:

a multi-layered coiled conductor;

a yoke formed on said conductor for providing a magnetic path to a magnetic field generated by said conductor;

said yoke including a tip, and a central portion that defines an optical opening; and said yoke tip being recessed relative to said conductor underside.

18. A coil according to claim 17, further including an insulation layer that covers said conductor at least in part; and

wherein said protective layer defines a tip that extends underneath said yoke tip.

19. A coil according to claim to any of claims 1, 2, 3, 4, 5, 8, 9, 17 or 18, wherein said pole tip has a ring-shaped footprint that is defined by two generally concentric edges: an outer edge, and an inner edge.

20. A thin-film coil for use in a flying magneto-optical data storage system comprising:

a coiled conductor formed on an undercoat layer having an underside;

a yoke formed on said conductor for providing a magnetic path to a magnetic field

generated by said conductor;

said yoke including a tip, an underside, and a central portion that defines an optical opening; and

said yoke tip underside being substantially flush with the undercoat layer underside for increasing the density of said magnetic field at a target distance from the coil.

21. A coil according to any of claims 1, 8, 17 or 20, wherein said yoke is generally formed of three sections: an upper section, an intermediate section, and said tip.

22. A coil according to claim 21, wherein said upper section extends integrally into said intermediate section;

wherein said intermediate section extends over an inner side of said conductor; and

wherein said intermediate section is generally conically shaped.

23. A coil according to claim 21, wherein said upper section extends integrally into said intermediate section;

wherein said intermediate section extends over an inner side of said conductor into said tip; and

wherein said tip is generally cylindrically shaped.

24. A coil according to any of claims 20, 21, 22 or 23 wherein said conductor includes a plurality of superimposed multi-layered turns.

25. A coil according to claim 24, wherein said conductor includes a first layer of turns and a second layer of turns; and

wherein said first layer is connected to one of said two contact pads and is coiled helically, inwardly, and terminates in an innermost terminal end;

wherein said second layer includes an innermost terminal end that overlays said innermost terminal end of said first layer in order to establish electrical contact therewith, and to ensure the continuity of an electrical path formed by said conductor.

26. A coil according to claim 25, wherein said second layer of turns is coiled in a plurality of concentric helical turns, similar to, and in the same coiling direction as said first layer of turns.

27. A coil according to any of claims 1, 8, 17 or 20, wherein said conductor is made of electrically conductive material and has a substantially uniform square cross-

sectional area along substantially its entire length.

28. A coil according to claim 27, wherein the cross-sectional area of said conductor ranges between approximately 8 microns and approximately 30 microns, and preferably between approximately 8 microns and approximately 16 microns.

29. A coil according to claim 21, wherein said yoke upper section and intermediate section have a substantially uniform thickness.

30. A coil according to claim 19. wherein said inner edge is formed of two arcuate sections and two linear sections: and

wherein said linear sections are generally tangential to said arcuate sections.

31. A coil according to claim 30, wherein said linear sections are symmetrical relative to a major axis M-M passing through a geometric center of said inner edge; and

wherein said arcuate sections are generally semi-circularly shaped and symmetrical relative to a minor axis passing through a geometric center C of said inner edge.

32. A coil according to claim 20. wherein said conductor includes an additional turn formed within said undercoat layer in close proximity to said yoke tip.

33. A coil according to any of claims 9 or 18, wherein said yoke further includes an outer section that extends over a peripheral side of said insulation layer.

34. A coil according to claim 33, wherein said yoke outer section extends in an enlarged toe section.

35. A coil according to any of claims 1. 2. 3, 4, 5, 8, 9, 17 or 20, wherein said conductor is coiled and comprises between approximately 15 and 40 turns.

36. A thin-film coil for use in a flying magneto-optical head, for transducing data to or from a data storage medium, comprising:

a multi-layered coiled conductor;

a yoke formed on said conductor for providing a magnetic path to a magnetic field generated by said conductor;

said yoke defining an optical opening;

the medium including an outer periphery: and

the coil being oriented at a predetermined angle relative to said outer periphery of the medium.

37. A thin-film coil according to claim 36, wherein said predetermined angle is approximately 90 degrees.

38. A thin-film coil according to claim 36, wherein said predetermined angle ranges between approximately +45 degrees to approximately -45 degrees.

39. A method of using a coil in a flying magneto-optical head having an optical element, for cooperating the passage of an optical beam through the coil, comprising the step of scanning the optical beam through an opening formed in the coil.

AMENDED CLAIMS

[received by the International Bureau on 25 September 1998 (25.09.98); original claims 1,3,17,20,36and 39 amended; new claims 40-69 added; remaining claims unchanged (9 pages)]

1. A coil for mounting on an optical or magneto-optical head including an optical element, to cooperate with the passage of an optical beam, the coil comprising:

a conductor; and

a yoke disposed intermediate the optical element and said conductor.

2. A coil according to claim 1, wherein said optical element includes a lens.

3. A coil according to claim 2, wherein the yoke is smaller than, or equal to said lens.

4. A coil according claim 1, wherein said conductor defines an elongated central passageway, and wherein said yoke defines an elongated passageway for the optical beam to pass through.

5. A coil according to any of claims 1, wherein said elongated passageways are generally co-axial, and wherein each of said elongated passageways defines a major axis for allowing the optical beam to be scanned therealong.

6. A coil according to any of claims 1, 2, 3, 4 or 5, wherein said yoke includes a sloped portion.

7. A coil assembly according to claim 5, wherein said sloped portion of said yoke extends at least in part within said elongated central passageway of said conductor.

8. A thin-film coil for use in an optical or magneto-optical head comprising:

a multi-layered coiled conductor having an underside;

a yoke formed on said conductor for providing a magnetic path to a magnetic field generated by said conductor;

said yoke including a tip, and a central portion that defines an optical opening; and

said yoke tip terminating in substantial close proximity to said conductor underside.

9. A coil according to claim 8, further including an insulation layer that covers said conductor at least in part.

10. A coil according to any of claims 8 or 9, further including a protective layer on which said conductor is formed for protecting said conductor underside, wherein said protective layer includes a passageway that coincides substantially

with said optical opening, and wherein said protective layer defines a tip that extends underneath said yoke tip.

11. A coil according to any of claims 1, 2, 3, 4, 5, 8 or 9, wherein said conductor and said yoke are generally elliptically or circularly shaped.

12. A coil according to any of claims 1, 2, 3, 4, 5, 8 or 9, wherein said conductor includes two pads for connection to an electrical circuit.

13. A coil according to any of claims 1, 2, 3, 4, 5, 8 or 9, wherein said yoke is made of a ferromagnetic material having a permeability of approximately 2000.

14. A coil according to any of claims 1, 2, 3, 4, 5, 8 or 9, wherein said yoke has a thickness ranging from approximately 4 um to approximately 6 um.

15. A coil according to any of claims 1, 2, 3, 4, 5, 8 or 9, wherein said conductor includes two layers that are spaced apart along a vertical direction by approximately 6 um.

16. A coil according to any of claims 1, 2, 3, 4, 5, 8 or 9, wherein said conductor has a cross-sectional area ranging between approximately 2 um^2 and 7 um^2.

17. A thin-film coil for use in an optical or magneto-optical head comprising:

a multi-layered coiled conductor;

a yoke formed on said conductor for providing a magnetic path to a magnetic field generated by said conductor;

said yoke including a tip, and a central portion that defines an optical opening; and

said yoke tip being recessed relative to said conductor underside.

18 A coil according to claim 17, further including an insulation layer that covers said conductor at least in part; and

wherein said protective layer defines a tip that extends underneath said yoke tip.

19. A coil according to claim to any of claims 1, 2, 3, 4, 5, 8, 9, 17 or 18, wherein said pole tip has a ring-shaped footprint that is defined by two generally concentric edges: an outer edge, and an inner edge.

20. A thin-film coil for use in an optical or magneto-optical data storage system comprising:

a coiled conductor formed on an undercoat layer having an underside;

a yoke formed on said conductor for providing a magnetic path to a magnetic field generated by said conductor;

said yoke including a tip, an underside, and a central portion that defines an optical opening; and

said yoke tip underside being substantially flush with the undercoat layer underside for increasing the density of said magnetic field at a target distance from the coil.

21. A coil according to any of claims 1, 8, 17 or 20, wherein said yoke is generally formed of three sections: an upper section, an intermediate section, and said tip.

22. A coil according to claim 21, wherein said upper section extends integrally into said intermediate section;

wherein said intermediate section extends over an inner side of said conductor; and

wherein said intermediate section is generally conically shaped.

23. A coil according to claim 21, wherein said upper section extends integrally into said intermediate section;

wherein said intermediate section extends over an inner side of said conductor into said tip; and

wherein said tip is generally cylindrically shaped.

24. A coil according to any of claims 20, 21, 22 or 23 wherein said conductor includes a plurality of superimposed multi-layered turns.

25. A coil according to claim 24, wherein said conductor includes a first layer of turns and a second layer of turns; and

wherein said first layer is connected to one of said two contact pads and is coiled helically, inwardly, and terminates in an innermost terminal end;

wherein said second layer includes an innermost terminal end that overlays said innermost terminal end of said first layer in order to establish electrical contact therewith, and to ensure the continuity of an electrical path formed by said conductor.

26. A coil according to claim 25, wherein said second layer of turns is coiled in a plurality of concentric helical turns, similar to, and in the same coiling direction as said first layer of turns.

27. A coil according to any of claims 1, 8, 17 or 20, wherein said conductor is made of electrically conductive material and has a substantially uniform square cross-sectional area along substantially its entire length.

28. A coil according to claim 27, wherein the cross-sectional area of said conductor ranges between approximately 8 microns and approximately 30 microns, and preferably between approximately 8 microns and approximately 16 microns.

29. A coil according to claim 21, wherein said yoke upper section and intermediate section have a substantially uniform thickness.

30. A coil according to claim 19, wherein said inner edge is formed of two arcuate sections and two linear sections; and

wherein said linear sections are generally tangential to said arcuate sections.

31 A coil according to claim 30, wherein said linear sections are symmetrical relative to a major axis M-M passing through a geometric center of said inner edge; and

wherein said arcuate sections are generally semi-circularly shaped and symmetrical relative to a minor axis passing through a geometric center C of said inner edge.

32. A coil according to claim 20, wherein said conductor includes an additional turn formed within said undercoat layer in close proximity to said yoke tip.

33. A coil according to any of claims 9 or 18, wherein said yoke further includes an outer section that extends over a peripheral side of said insulation layer.

34. A coil according to claim 33, wherein said yoke outer section extends in an enlarged toe section.

35. A coil according to any of claims 1, 2, 3, 4, 5, 8, 9, 17 or 20, wherein said conductor is coiled and comprises between approximately 15 and 40 turns.

36. A thin-film coil for use in an optical or magneto-optical head, for transducing data to or from a data storage medium, comprising:

a multi-layered coiled conductor;

a yoke formed on said conductor for providing a magnetic path to a magnetic field generated by said conductor;

said yoke defining an optical opening;

the medium including an outer periphery; and

the coil being oriented at a predetermined angle relative to said outer periphery of the medium.

37. A thin-film coil according to claim 36, wherein said predetermined angle is approximately 90 degrees.

38. A thin-film coil according to claim 36, wherein said predetermined angle ranges between approximately +45 degrees to approximately -45 degrees.

39. A method of using a coil in an optical or magneto-optical head having an optical element, for cooperating the passage of an optical beam through the coil, comprising the step of scanning the optical beam through an opening formed in the coil.

40. A coil for use in an optical or magneto-optical head, comprising:

a yoke formed of a tapered portion and an upper section;

said tapered portion defining a central passage; and

a thin-film conductor formed of a plurality of turns covered at least in part by, and disposed in proximity to said yoke upper section, and of at least one turn disposed in proximity to said yoke tapered section,

wherein said yoke upper section provides a path for a magnetic field generated by said plurality of turns when an electric current is flown through said conductor.

41. A coil according to claim 40, wherein said conductor includes a multi-layered coil conductor, and further includes a plurality of turns disposed in proximity to said yoke tapered section.

42. A coil according to claim 41, wherein said conductor is a two-layered coiled conductor.

43. A coil according to claim 40, wherein said yoke upper section is generally flat.

44. A coil according to claim 43, wherein said yoke upper section is generally annularly shaped.

45. A coil according to claim 40, wherein the head includes an attachment surface; and

wherein said yoke upper surface is secured to said attachment surface.

46. A coil according to claim 45, wherein the head includes an optical beam source that generates an optical beam; and

wherein said optical beam passes through said central passage defined by said yoke tapered portion.

47. A coil according to claim 46, wherein said central passage is elongated for allowing said optical beam to be deflected relative to said central passage.

48. A coil according to claim 40, wherein the head includes a lens having an outer perimeter, and wherein the coil is smaller than said lens outer perimeter.

49. A coil according to claim 40, further including an insulation layer that covers at least a part of said conductor.

50. A coil according to claim 40, further including a protective layer on which said conductor is formed.

51. A coil according to claim 50, wherein said protective layer defines an opening which is disposed in substantial axial registration relative to said yoke central passage.

52. A coil according to claim 51, wherein said protective layer defines a tip portion that surrounds said protective layer opening;

wherein said yoke tapered portion defines a tip that surrounds said yoke central passage; and

wherein said tapered portion tip contacts said protective layer tip portion.

53. A coil according to claim 51, wherein said protective layer defines a tip portion that surrounds said protective layer opening;

wherein said yoke tapered portion defines a tip that surrounds said yoke central passage; and

wherein said tapered portion tip terminates in close proximity to said protective layer tip portion.

54. A coil according to claim 51, wherein said protective layer defines a tip portion that surrounds said protective layer opening;

wherein said yoke tapered portion defines a tip that surrounds said yoke central passage; and

wherein said tapered portion tip is recessed relative to said protective layer tip portion.

55. A coil according to claim 54, further including an insulation layer that covers at least a part of said conductor and that defines a tip; and

wherein said insulation layer tip is interposed between said tapered portion tip and said protective layer tip portion.

56. A coil according to claim 40, wherein said yoke tapered portion includes a tip defined by an outer edge and an inner edge;

wherein said outer edge and said inner edge are separated by a radial distance "d" that defines a footprint of said yoke tip.

57. A coil according to claim 56, wherein said outer edge and said inner edge are generally concentric.

58. A coil according to claim 56, further including an insulation layer that covers at least a part of said conductor;

wherein said insulation layer defines an opening which is disposed in substantial axial registration relative to said yoke central passage; and

wherein said inner edge is disposed close proximity to said insulation layer opening.

59. A coil according to claim 40, wherein said conductor includes two pads.

60. A coil according to claim 40, wherein said conductors includes at least two layers; and

wherein said layers are spaced apart in a vertical direction by approximately 6 microns.

61. A coil according to claim 40, wherein said yoke has a generally uniform thickness; and

wherein said yoke thickness ranges between approximately 4 microns and approximately 6 microns.

62. A coil according to claim 40, wherein said conductor has a generally uniform thickness; and

wherein said conductor thickness ranges between approximately 2 microns and 7 microns.

63. A coil according to claim 40, wherein said conductor is coiled and is generally elliptically shaped; and

wherein said yoke is generally elliptically shaped.

64. A coil according to claim 40, wherein said conductor is coiled and is generally circularly shaped; and

wherein said yoke is generally circularly shaped.

65. A coil according to claim 40, wherein said conductor includes between 15 and 57 turns.

66. A coil according to claim 40, wherein said conductor has a cross-sectional area ranging between approximately 2 microns^2 and 7 microns^2.

67. A method of using a coil in an optical or magneto-optical head having an attachment surface, comprising:

securing the coil to the attachment surface for allowing an optical beam to pass through the coil,

wherein the coil includes:

a yoke formed of a tapered portion and an upper section;

said tapered portion defining a central passage; and

a thin-film conductor formed of a plurality of turns covered at least in part by, and disposed in proximity to said yoke upper section, and of at least one turn disposed in proximity to said yoke tapered section, so that said yoke upper section provides a path for a magnetic field generated by said plurality of turns when an electric current is flown through said conductor

68. A method according to claim 67, further including deflecting said optical beam relative to said central passage.

69. A coil for use in an optical or magneto-optical head, comprising:

a yoke formed of a central portion and an upper section;

said central portion defining a central passage; and

a thin-film conductor formed of a plurality of turns covered at least in part by, and disposed in proximity to said yoke upper section, and of at least one turn disposed in proximity to said yoke central section,

wherein said yoke upper section provides a path for a magnetic field generated by said plurality of turns when an electric current is flown through said conductor.

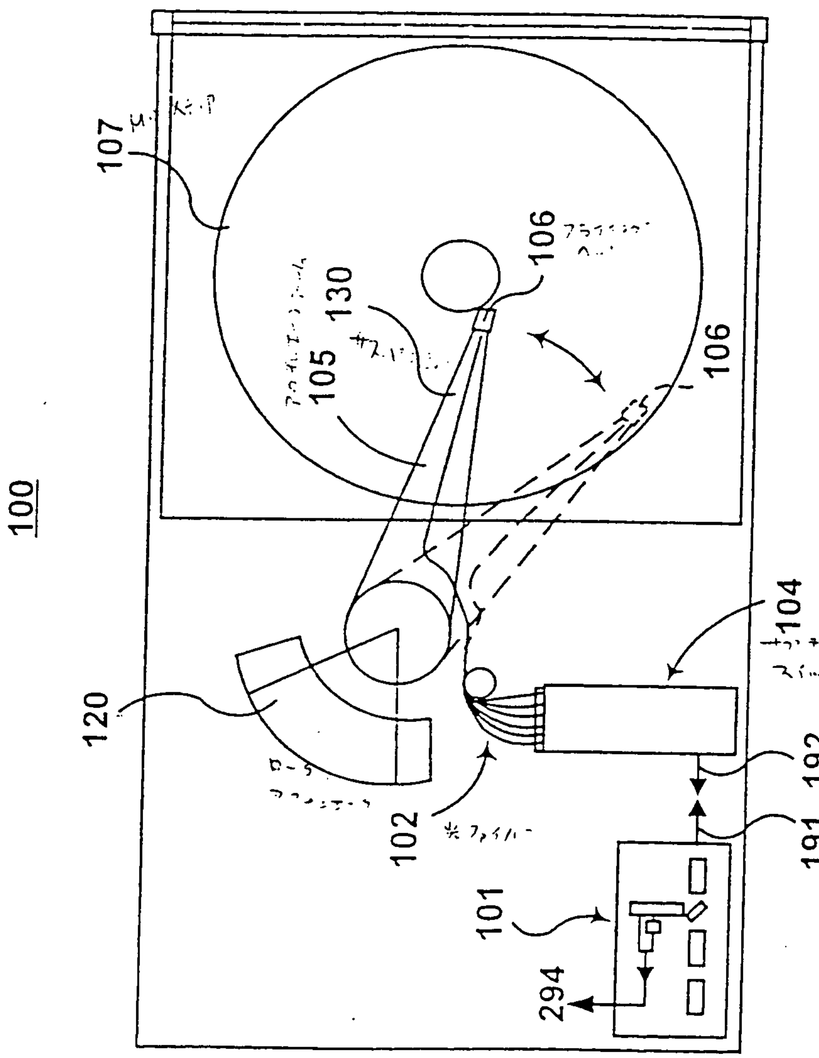


FIG. 1

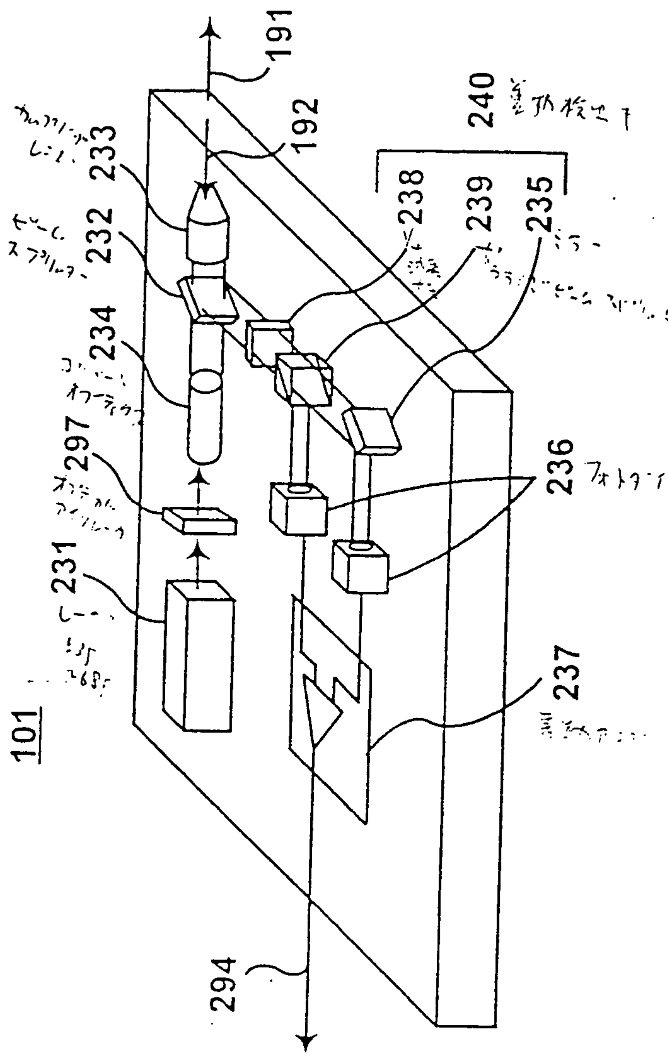


FIG. 2

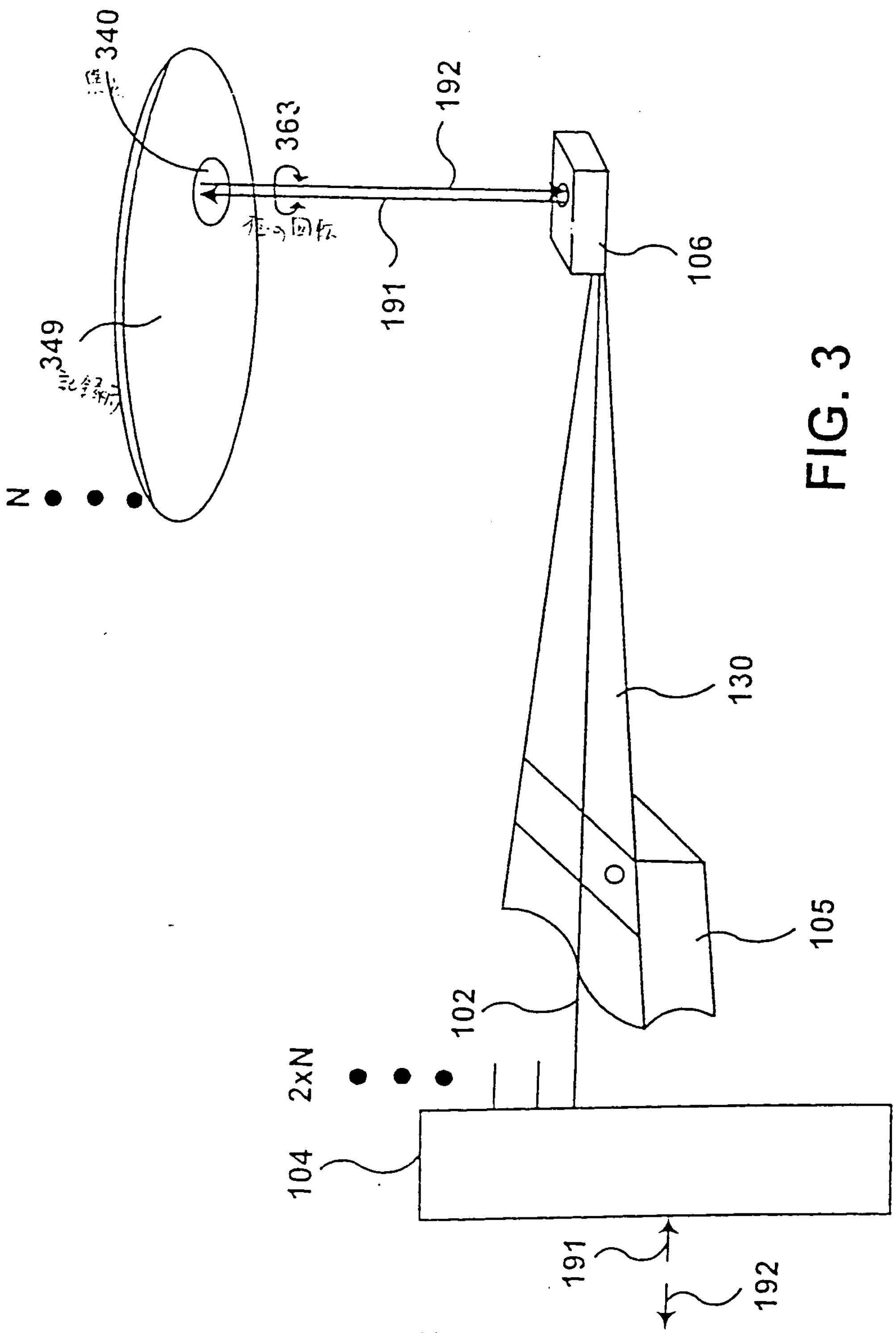


FIG. 3

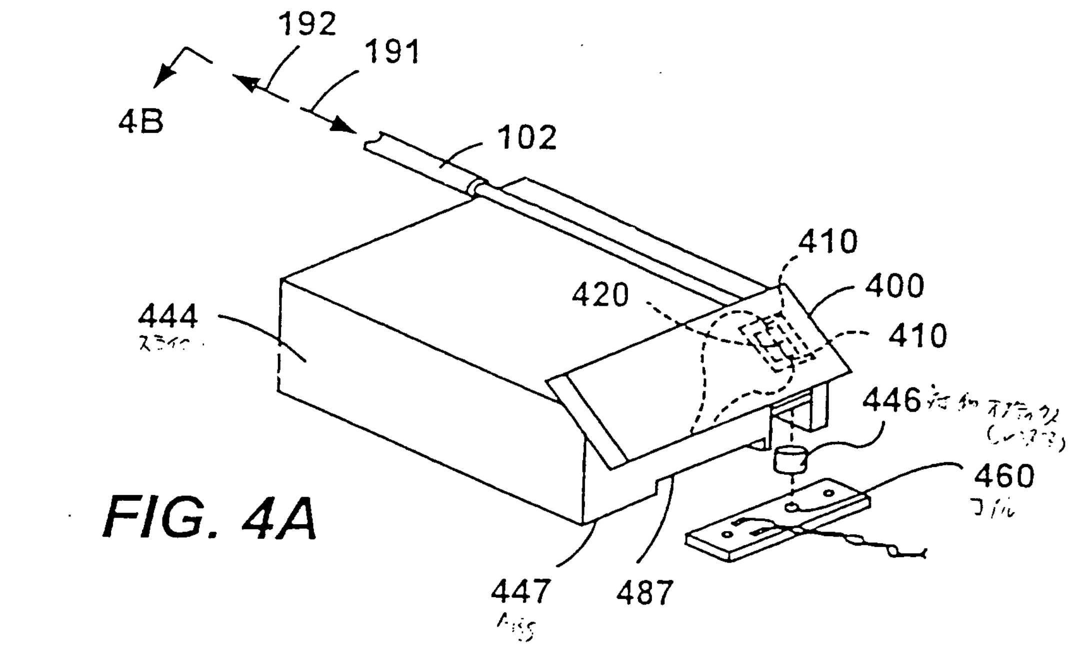

192
191
4B
102
410
420
400
410
444
446
460
447
487

FIG. 4A

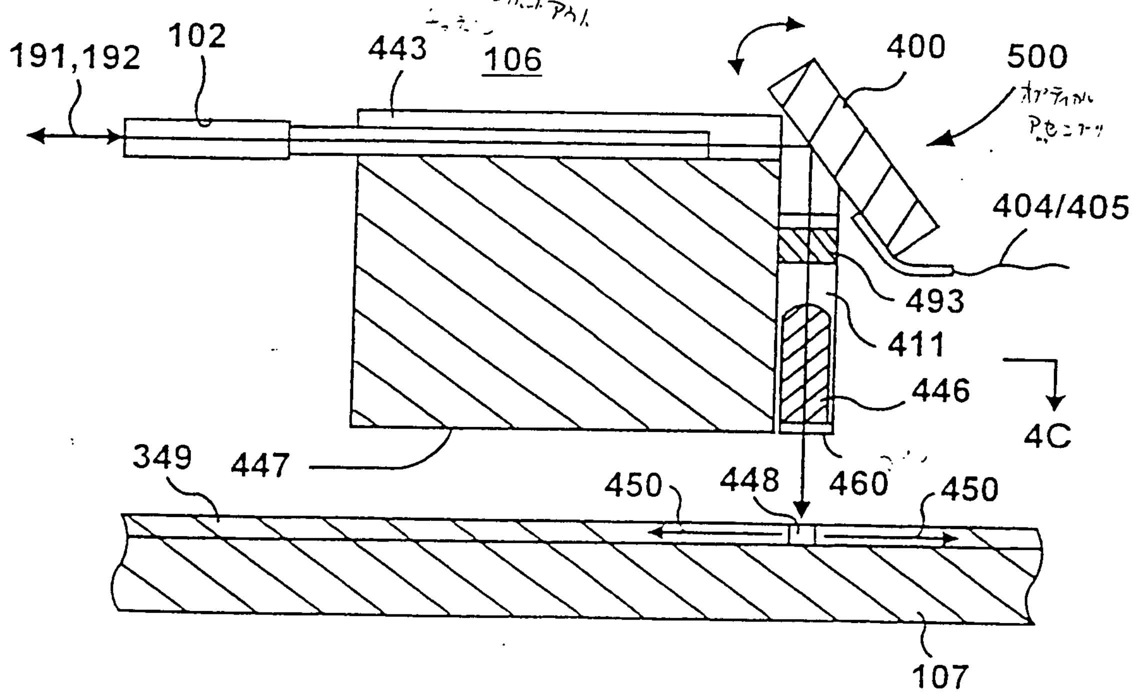

191,192
102
443
106
400
500
404/405
493
411
446
4C
349
447
450
448
460
450
107

FIG. 4B

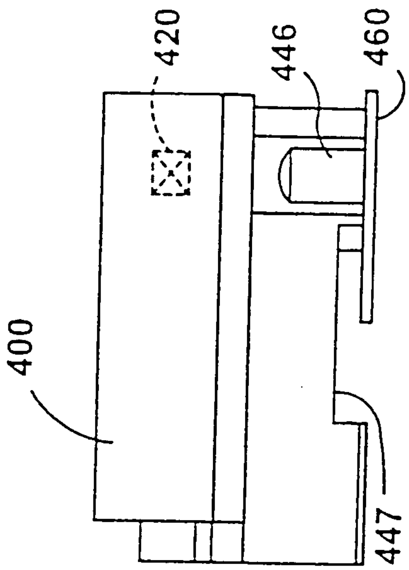


FIG. 4E

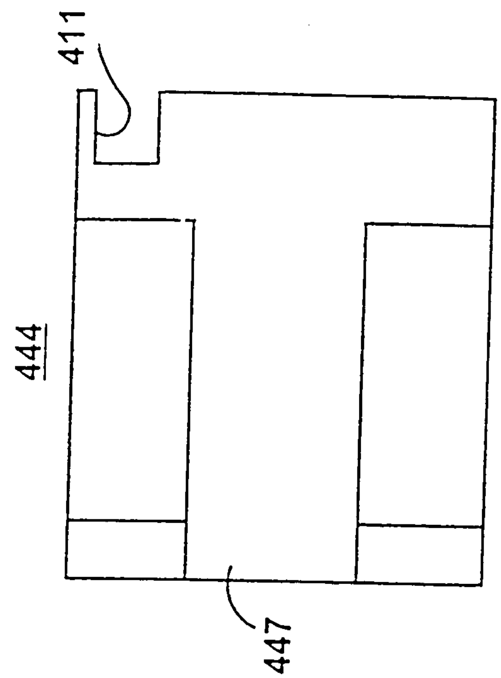


FIG. 4F

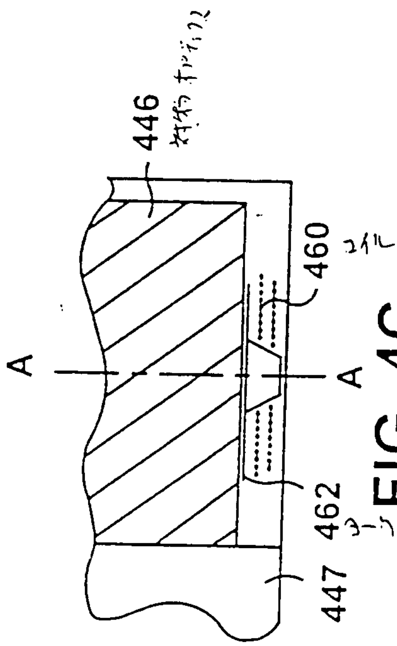


FIG. 4C

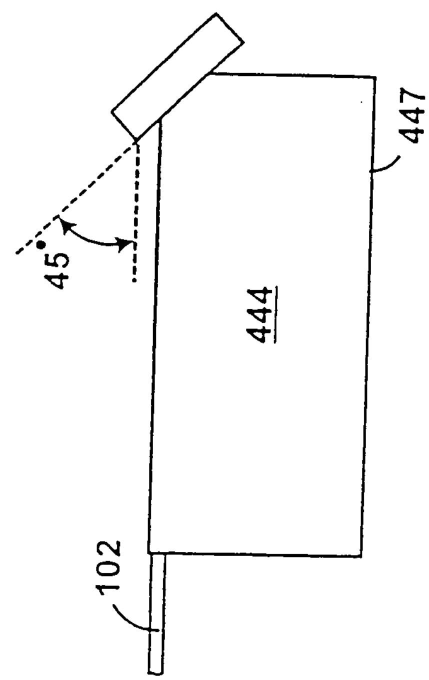


FIG. 4D

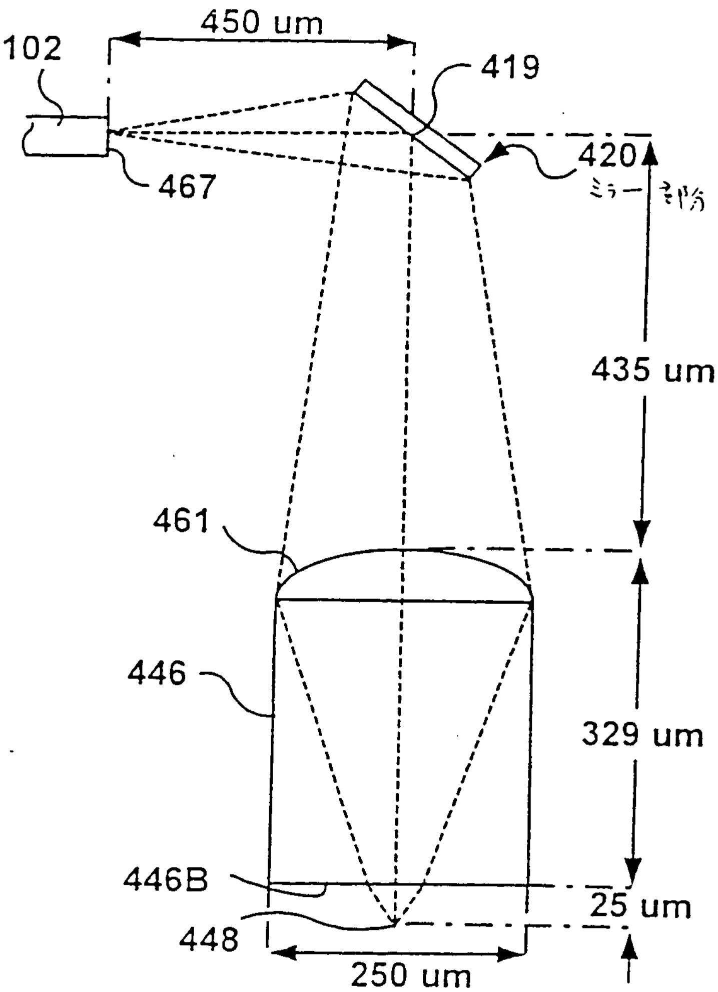

450 um
102
419
420
ミラー部分
467
435 um
461
446
329 um
446B
25 um
448
250 um

FIG. 5

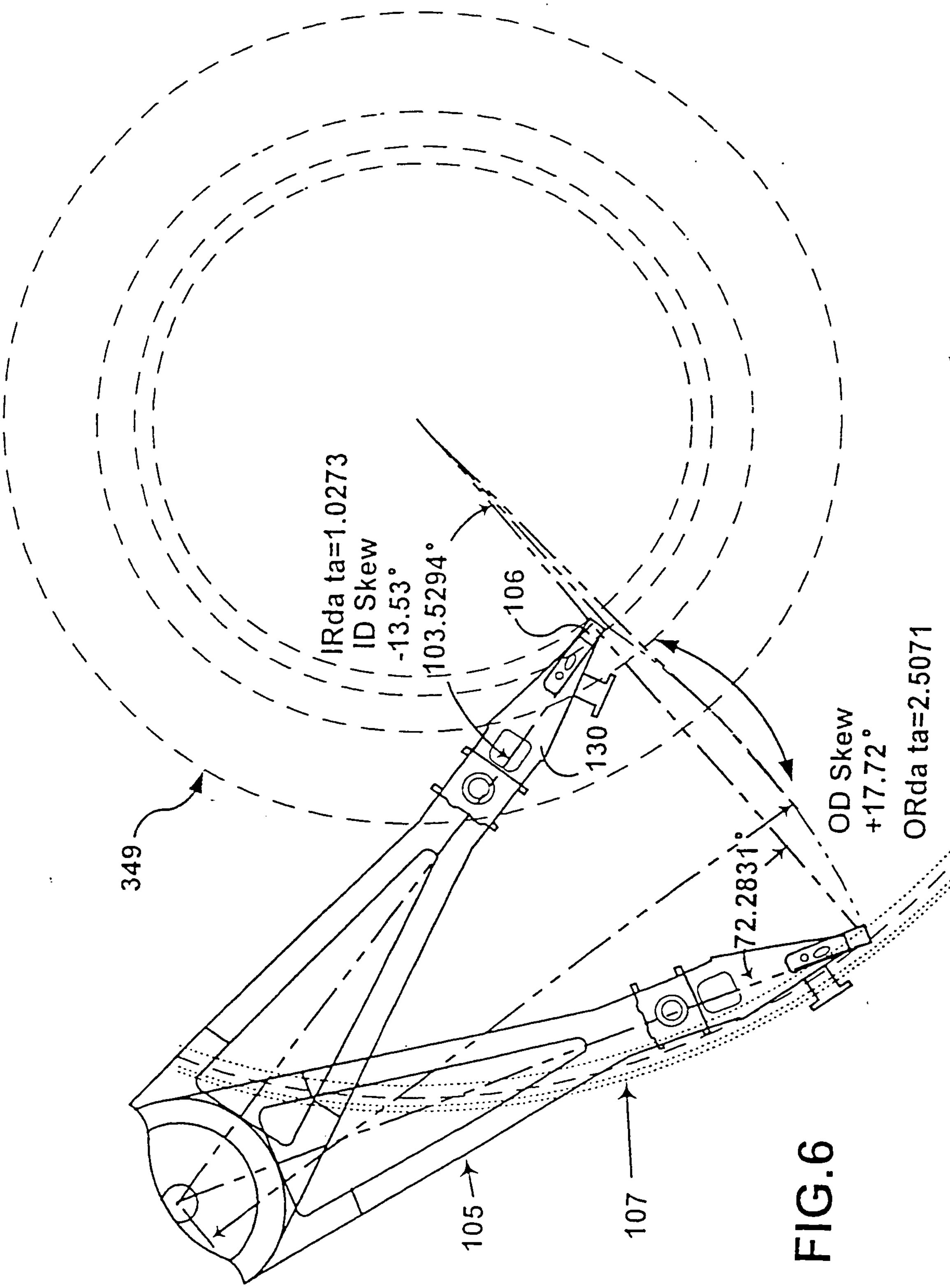

IRda ta=1.0273
ID Skew
-13.53°
103.5294°
106
130
349
72.2831°
OD Skew
+17.72°
ORda ta=2.5071
105
107

FIG.6

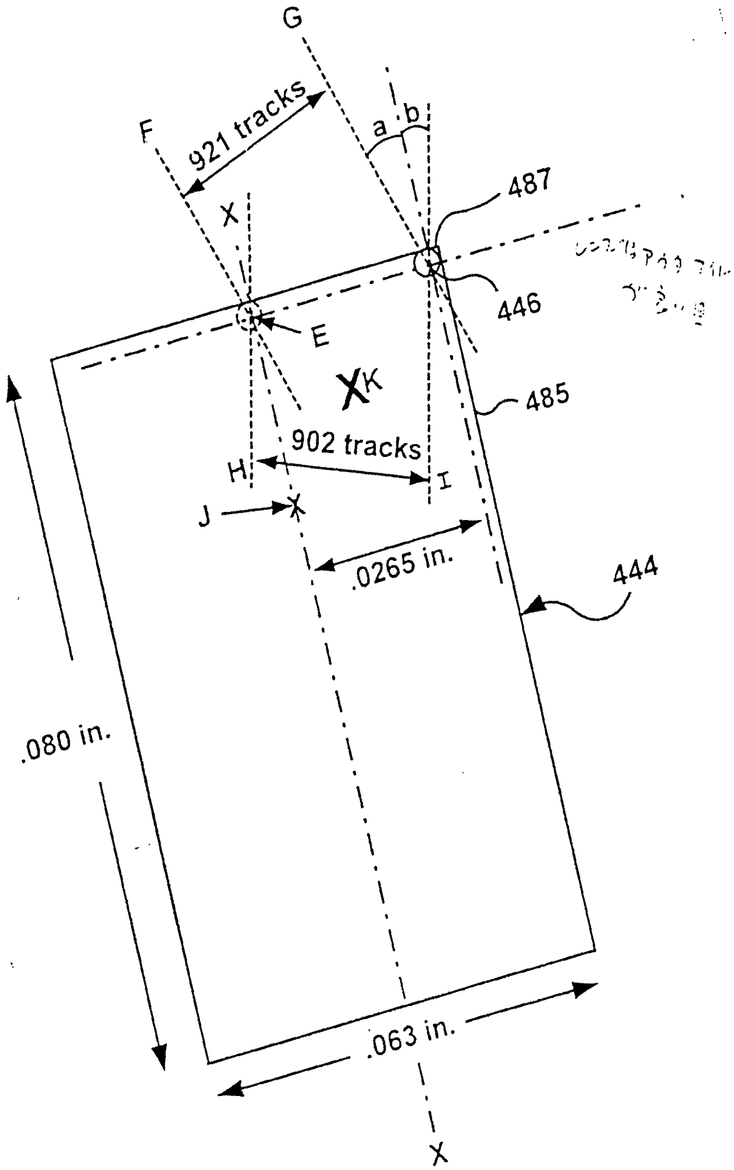

G
921 tracks
F
a
b
X
487
E
446
X K
485
902 tracks
H
I
J
.0265 in.
444
.080 in.
.063 in.
X

FIG. 7

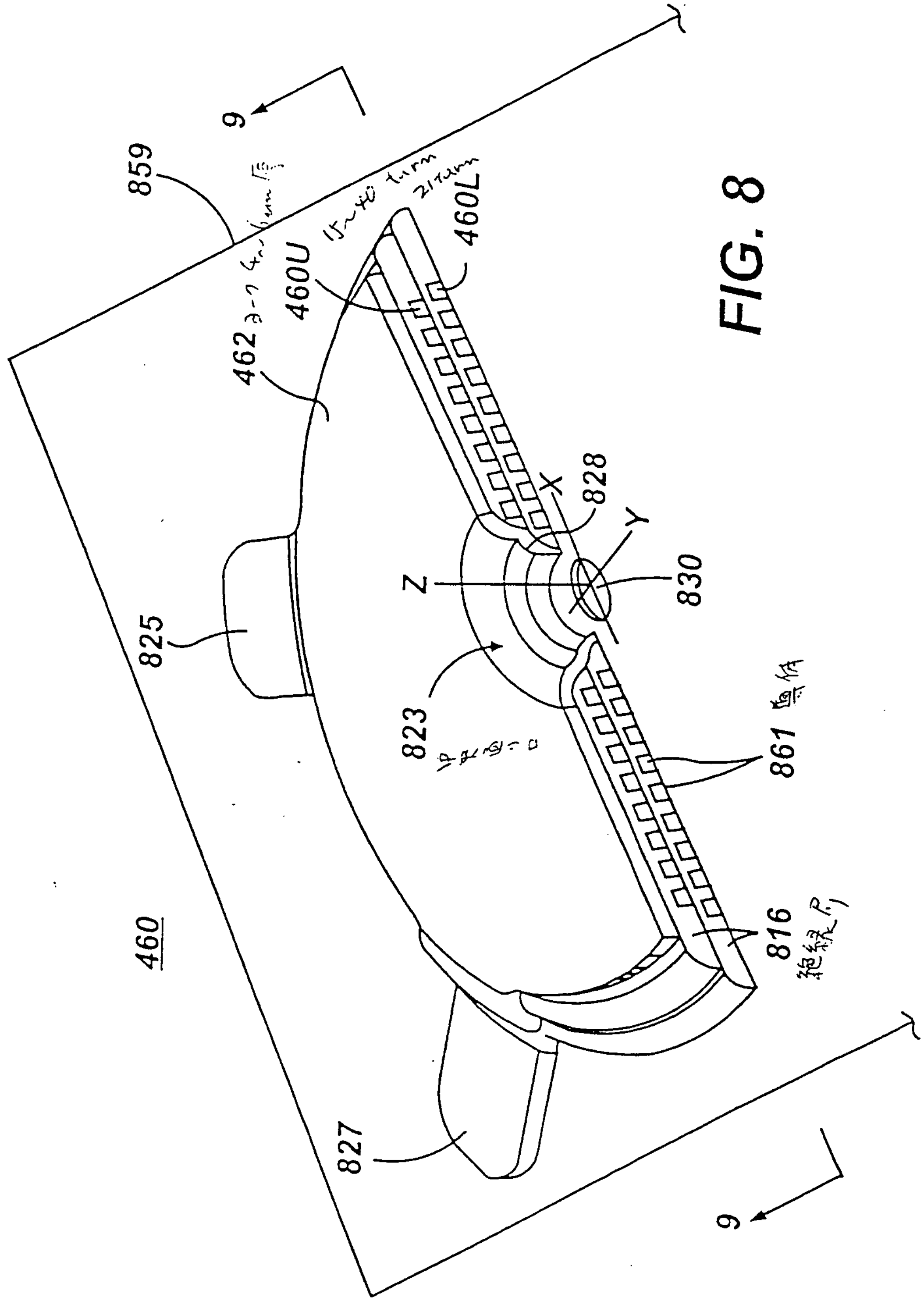


FIG. 8

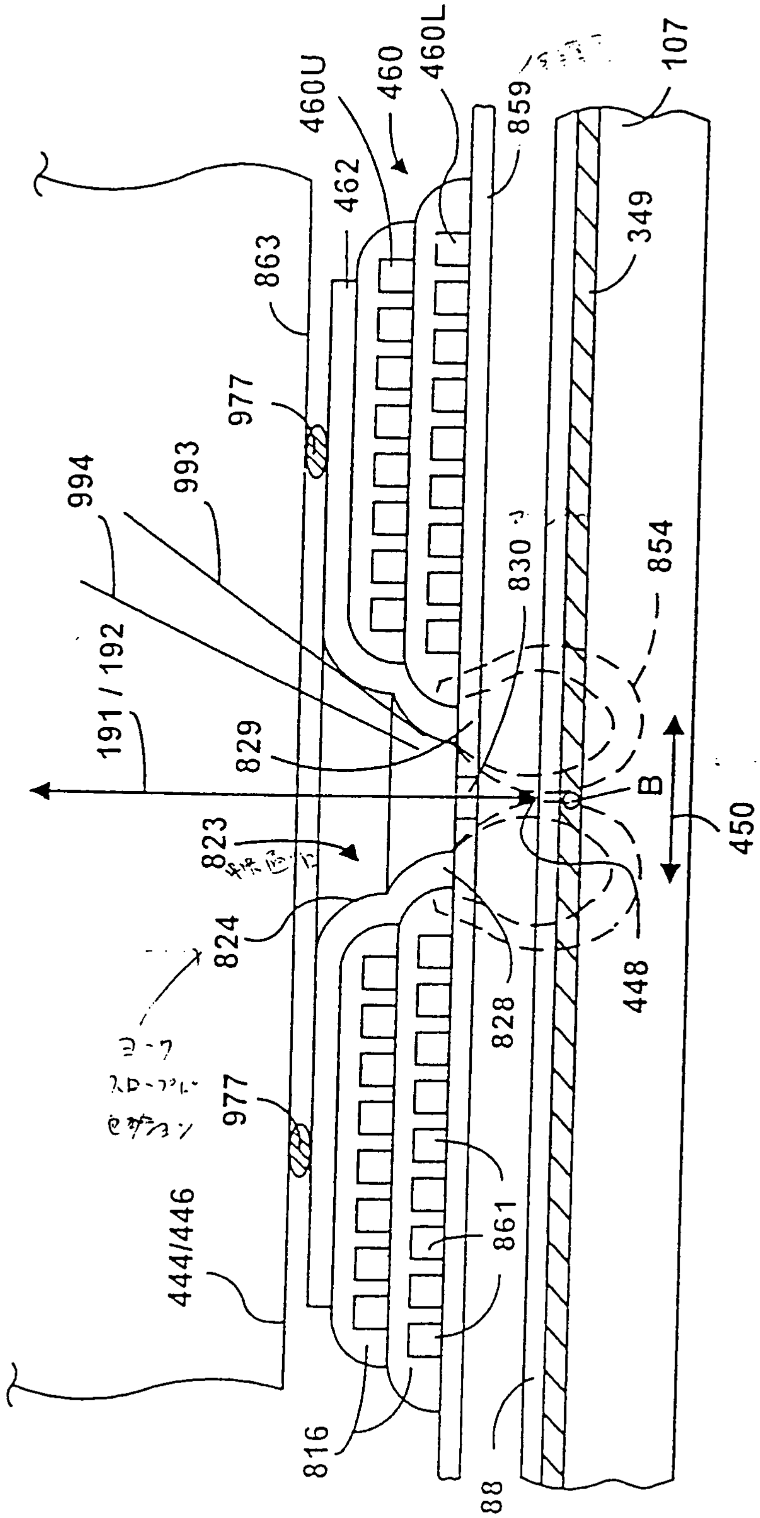

107
460L
460
460U
859
462
349
863
977
993
994
830
854
191 / 192
829
B
450
823
824
448
828
977
861
444/446
816
888

FIG. 9

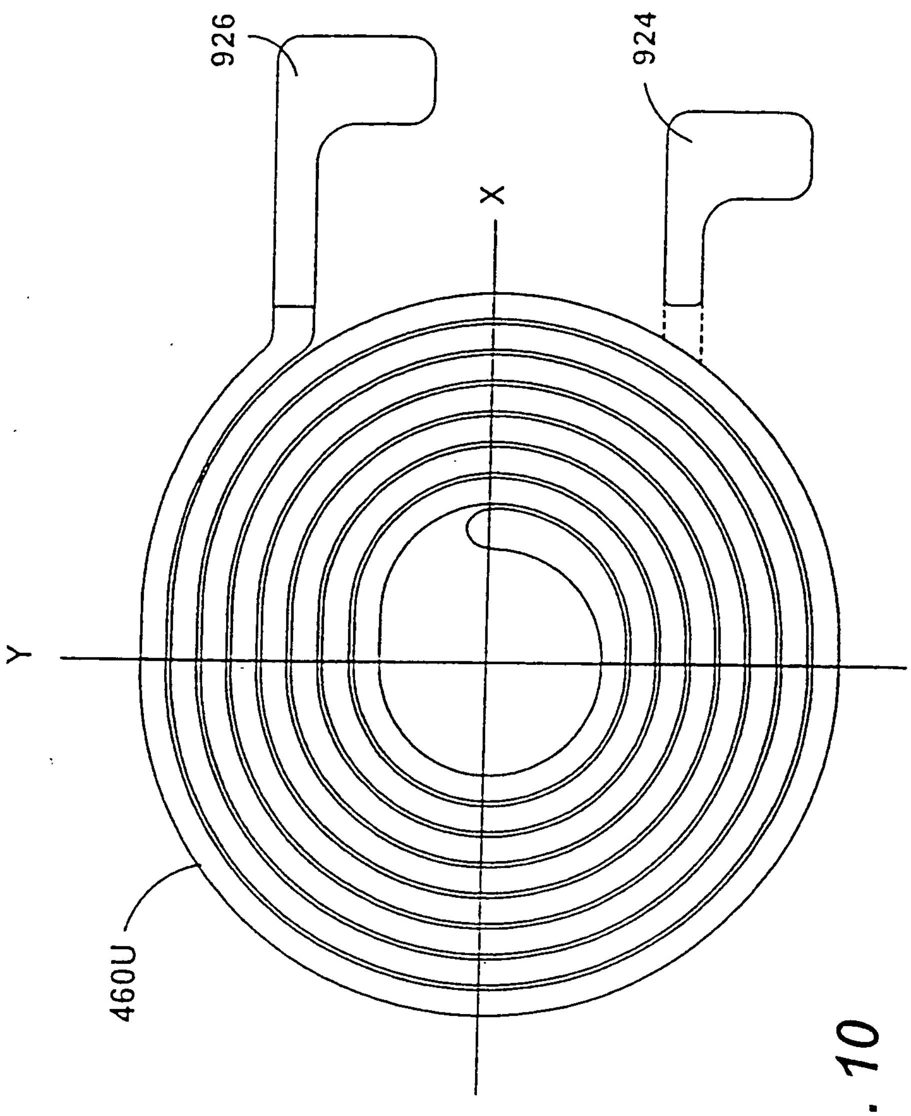


FIG. 10

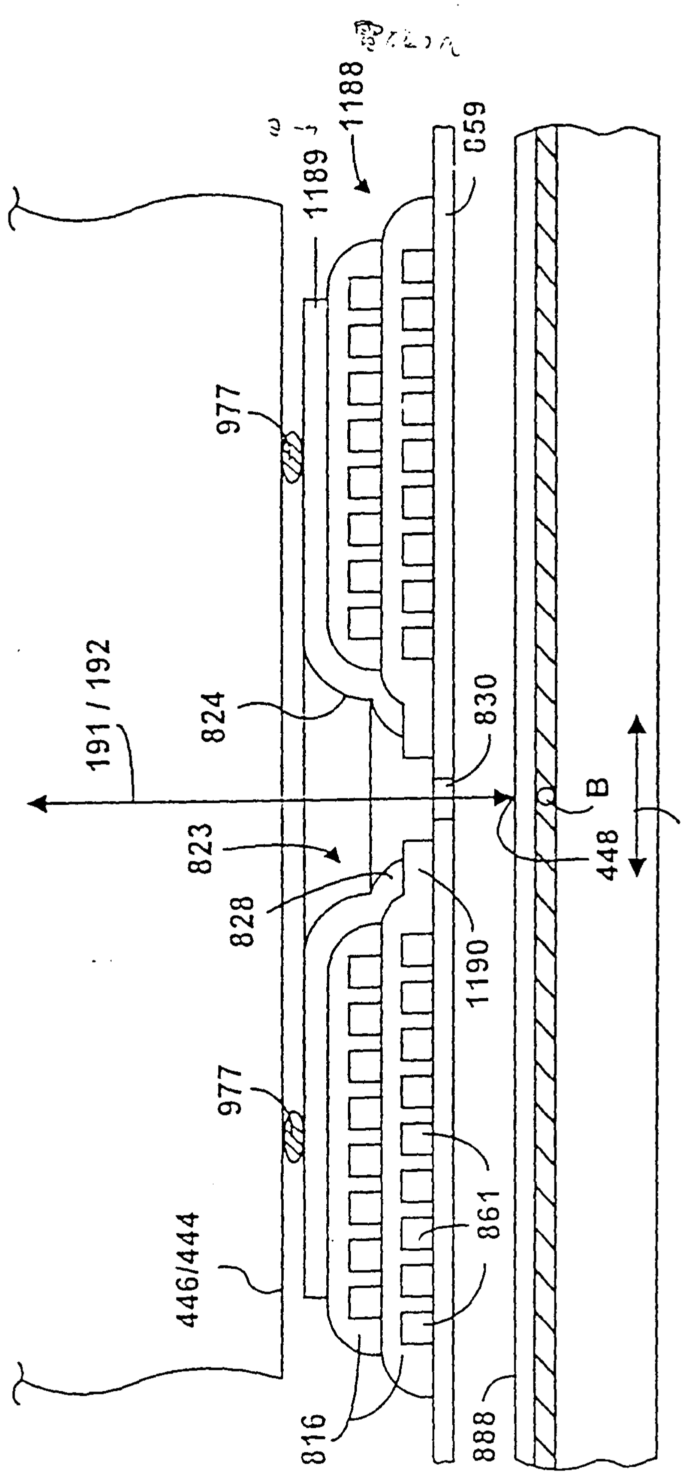

1188
1189
659
977
824
191 / 192
830
B
823
448
450
828
1190
977
861
446/444
816
888

FIG. 11

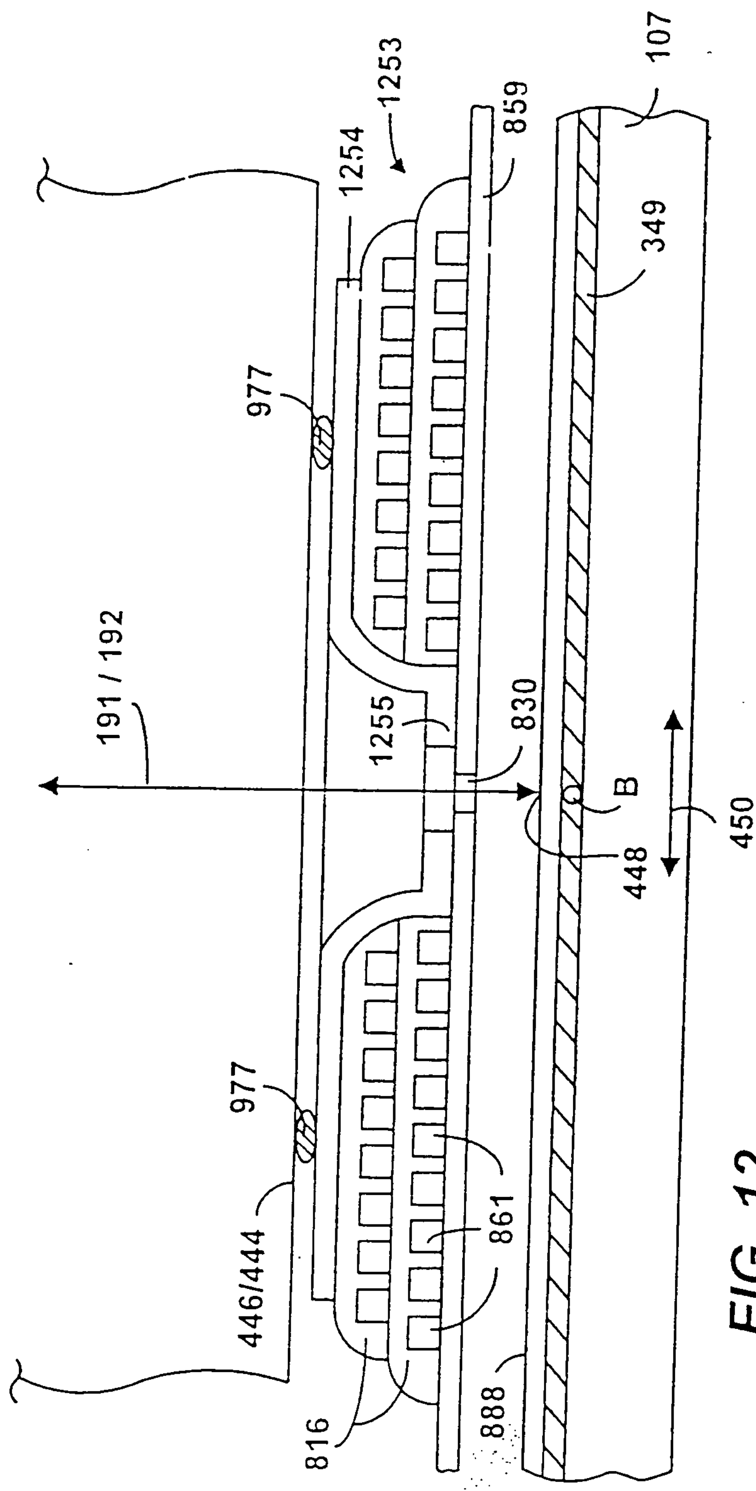

107
1253
859
1254
349
977
191 / 192
1255
830
B
448
450
977
446/444
861
816
888

FIG. 12

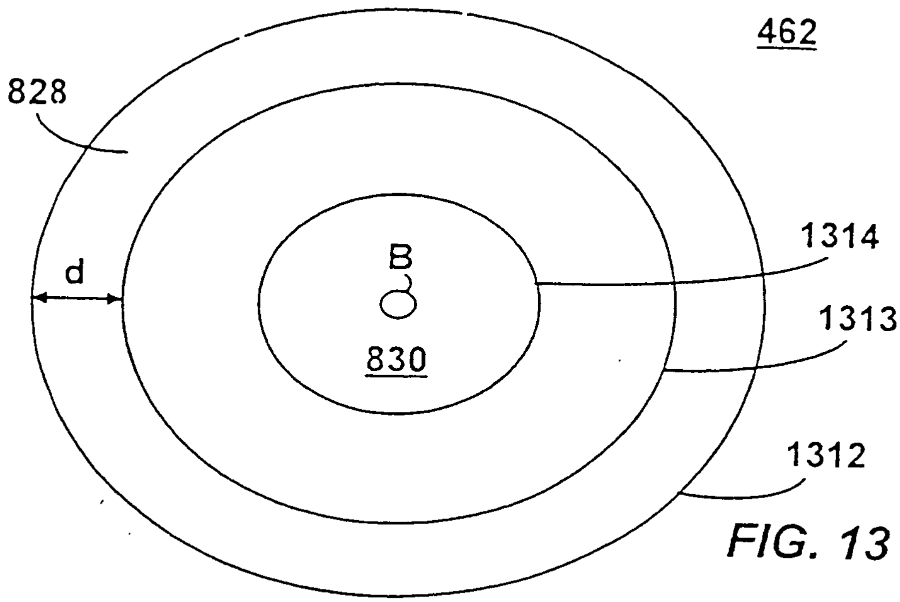

462
828
d
B
830
1314
1313
1312

FIG. 13

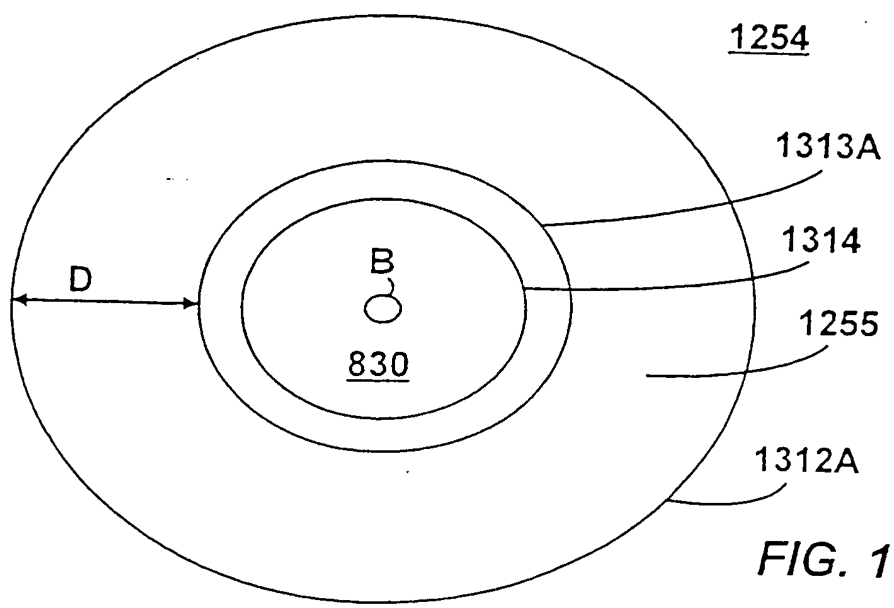

1254
1313A
D
B
1314
830
1255
1312A

FIG. 14

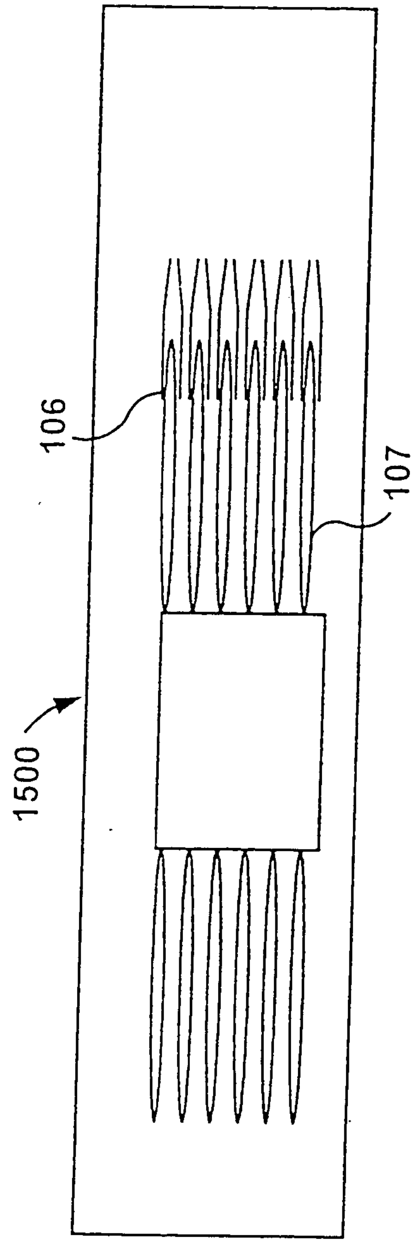


FIG. 15A

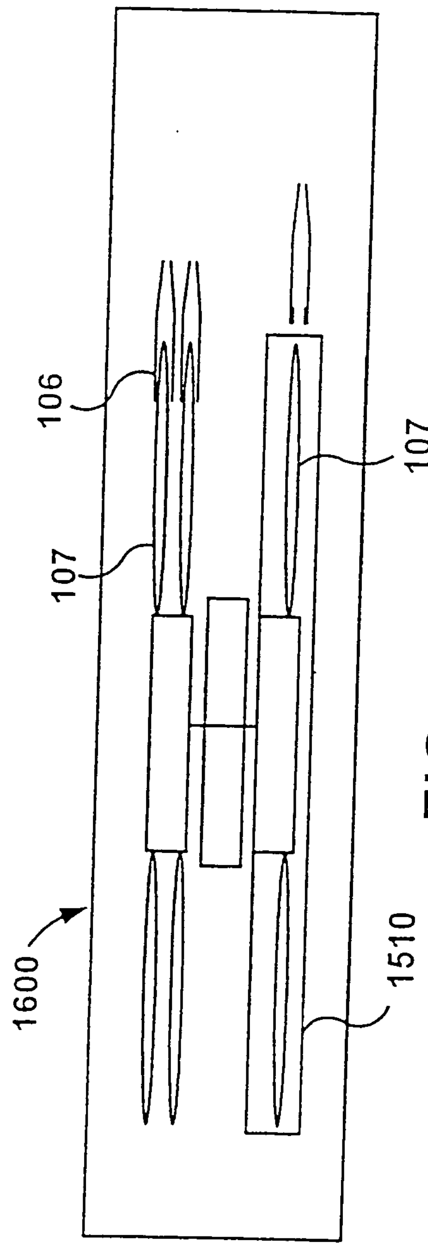


FIG. 15B

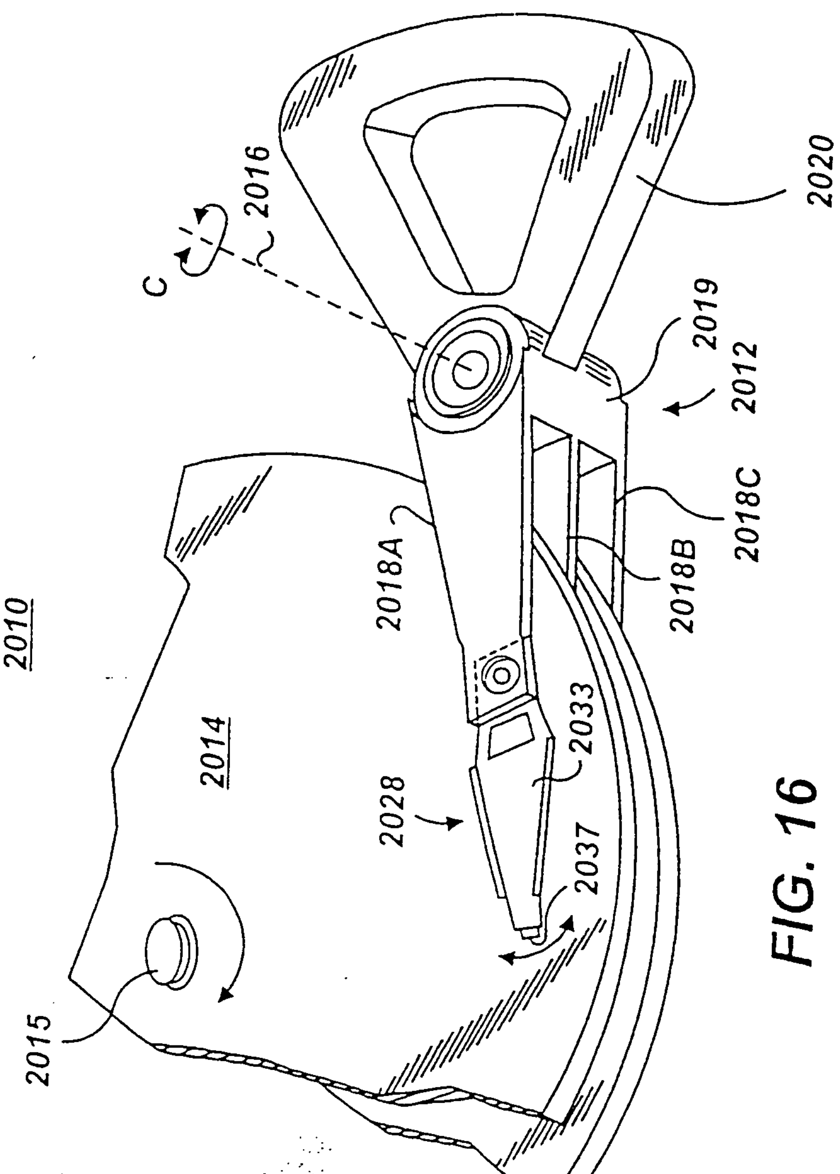

2010
2014
2015
2016
C
2020
2019
2012
2018A
2018B
2018C
2028
2033
2037

FIG. 16

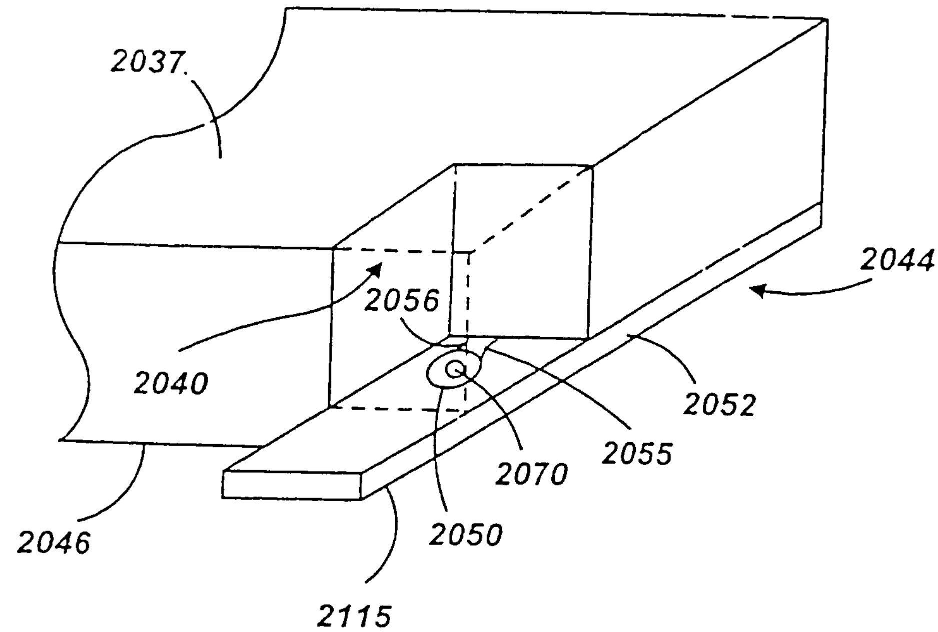


FIG.17

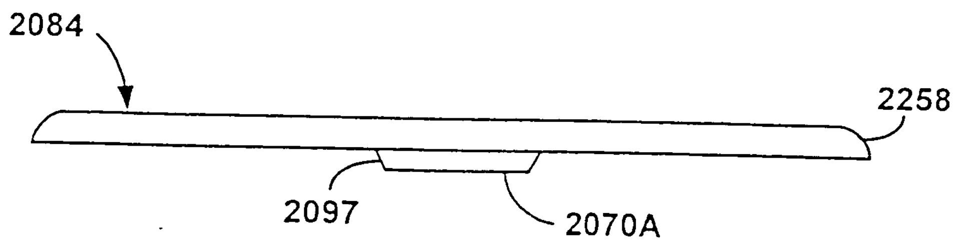


FIG. 24

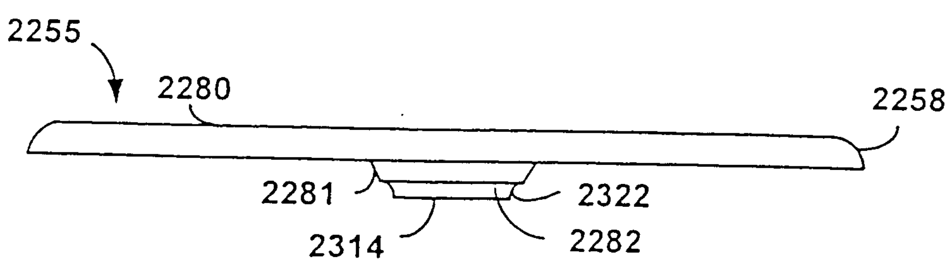


FIG. 25B

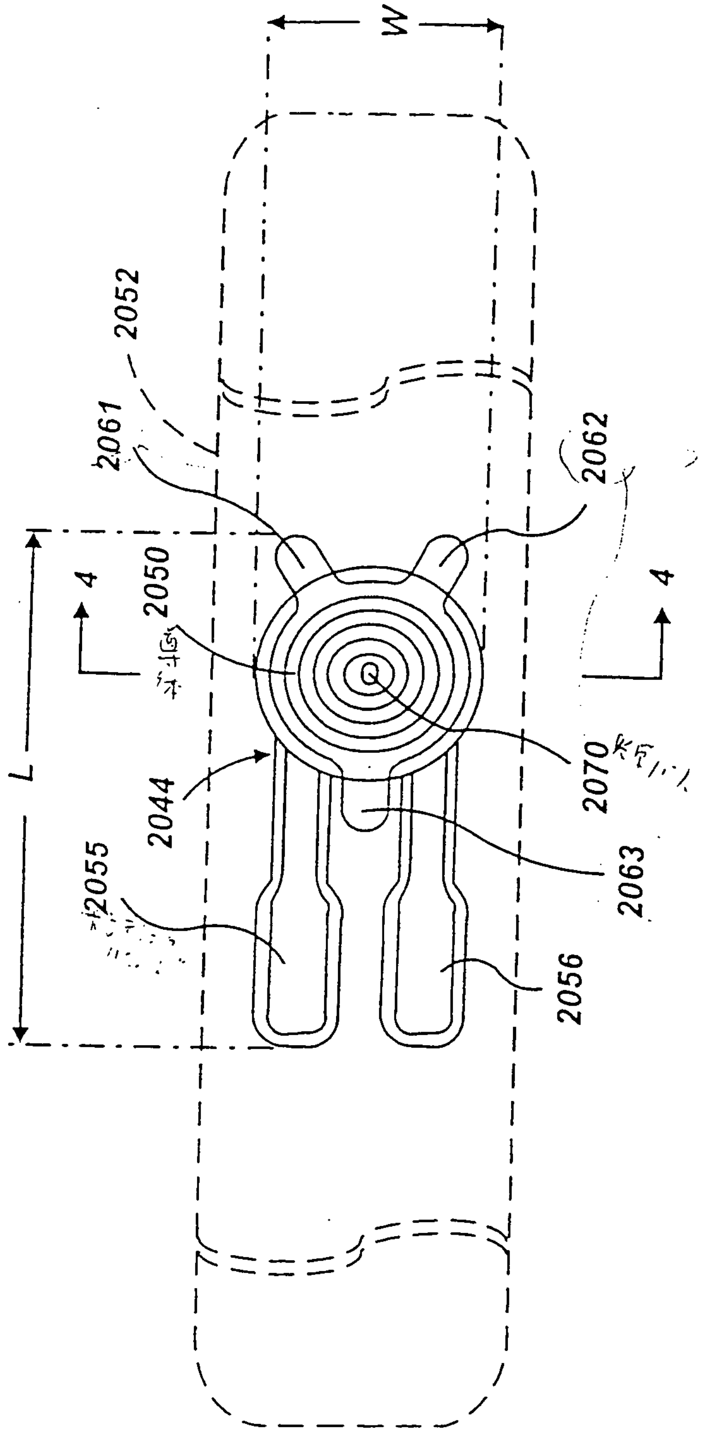


FIG. 18

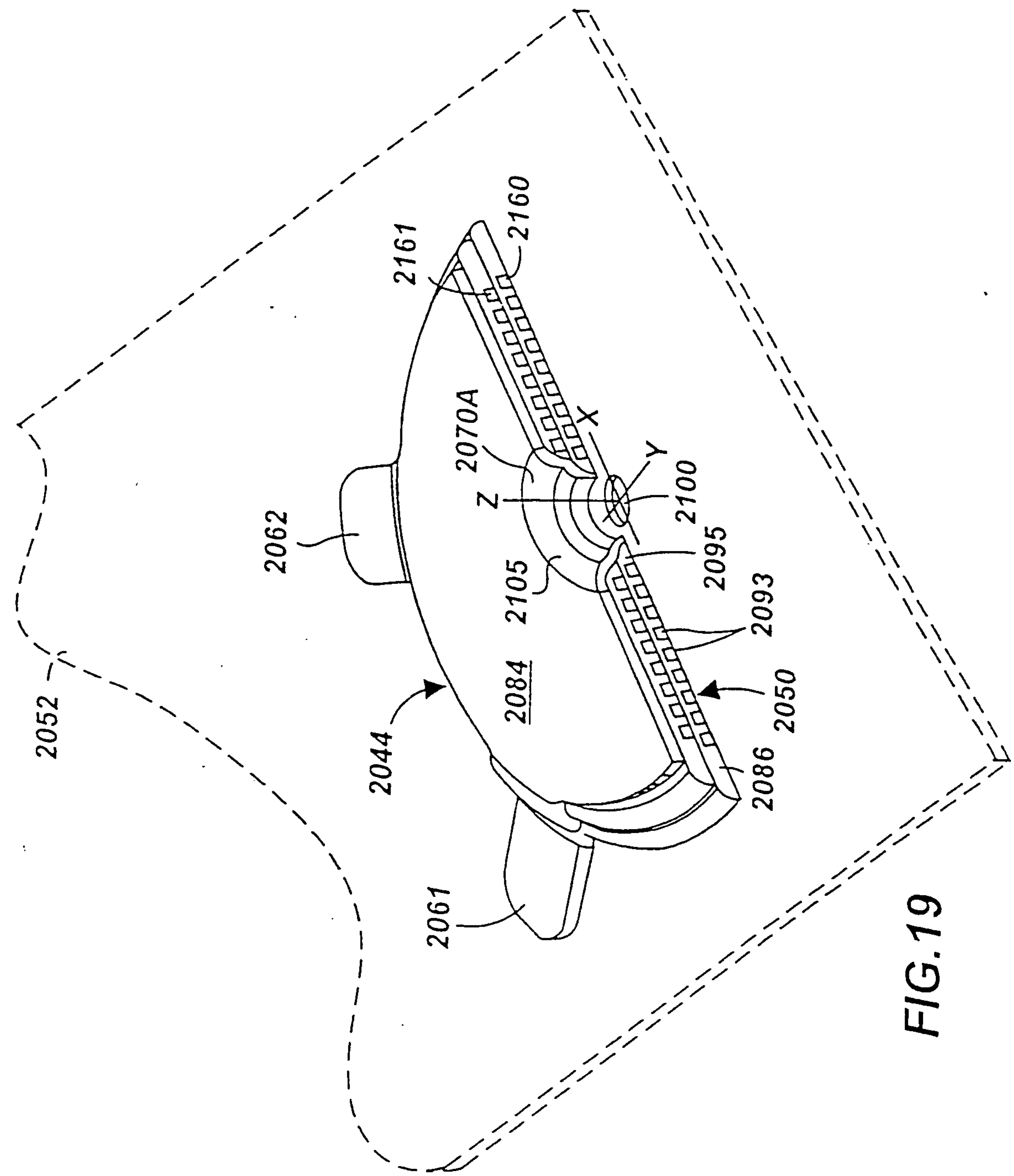

2160
2161
2070A
X
Y
Z
2100
2095
2093
2105
2062
2084
2050
2086
2044
2052
2061

FIG.19

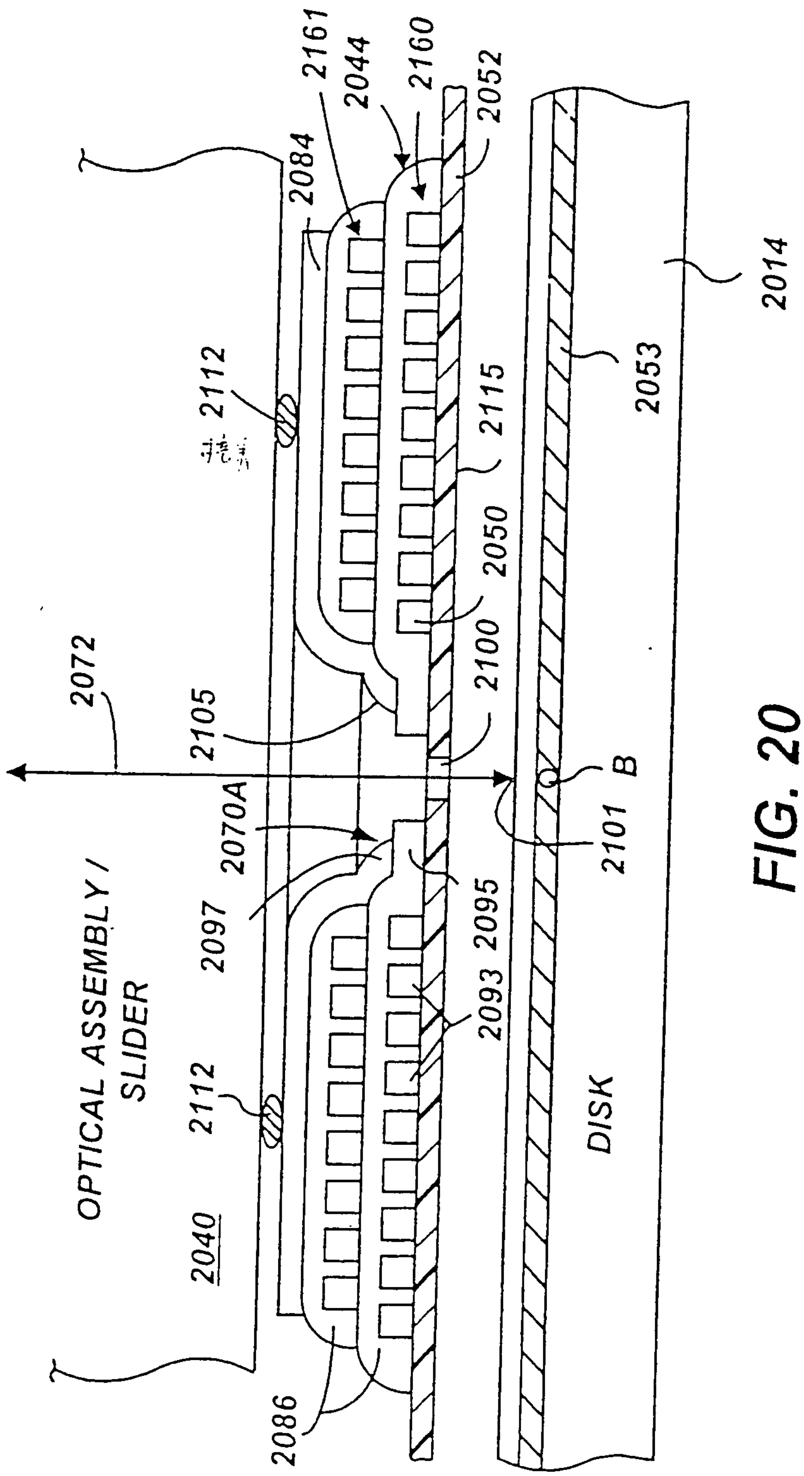
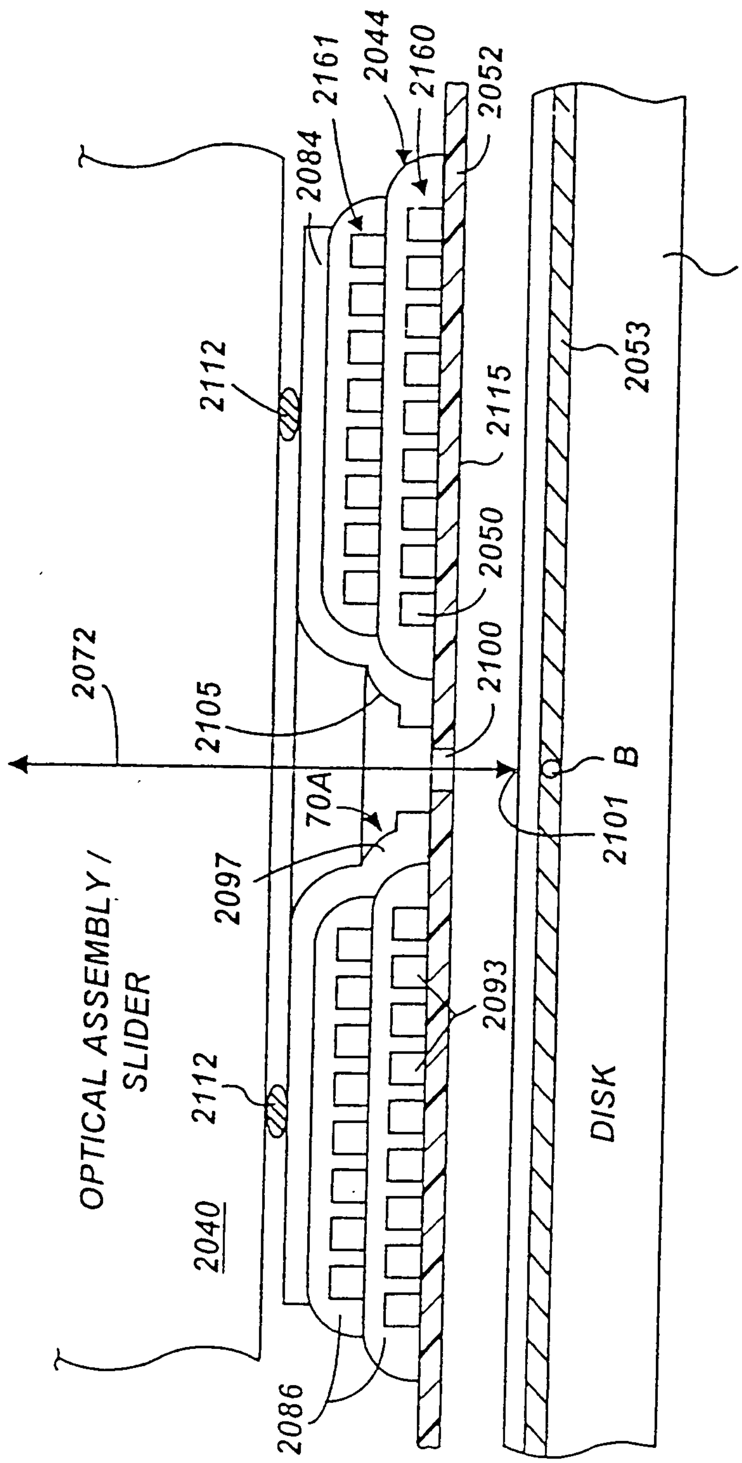

2161
2044
2160
2052
2084
2014
2112
2115
2053
2050
2072
2100
2105
B
2070A
2101
2097
2095
2093
OPTICAL ASSEMBLY /
SLIDER
2112
DISK
2040
2086

FIG. 20



OPTICAL ASSEMBLY / SLIDER
2040
2112
2112
2084
2161
2044
2160
2052
2014
2053
2115
2050
2100
2072
2105
B
70A
2101
2097
2093
DISK
2086

FIG. 20A

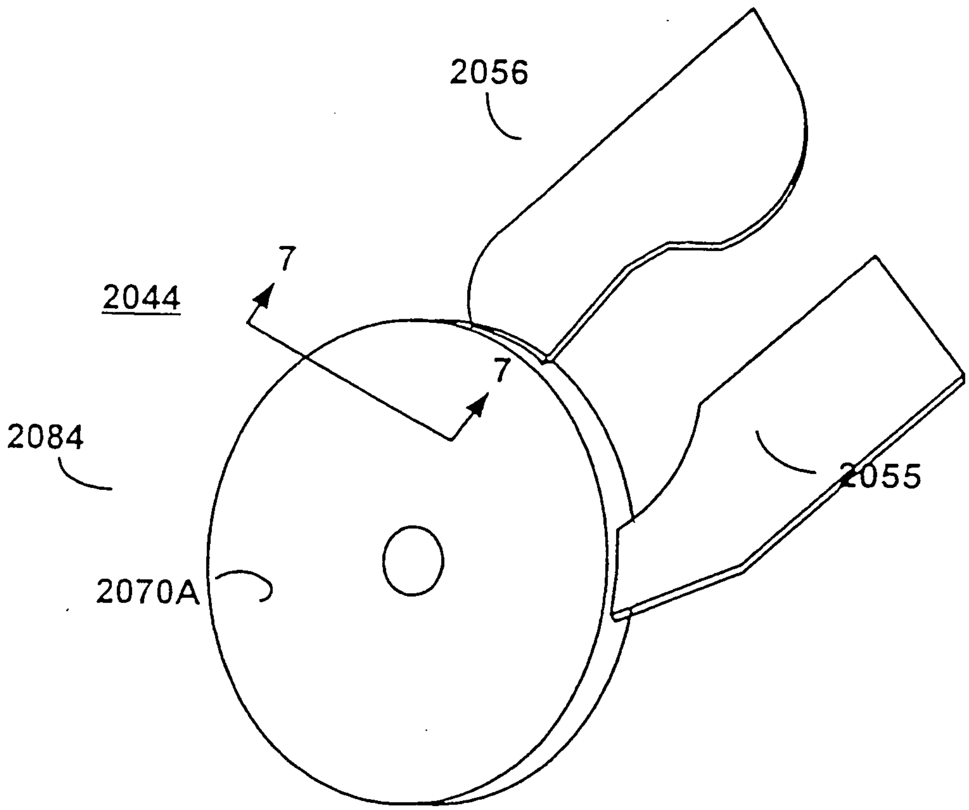


FIG. 21

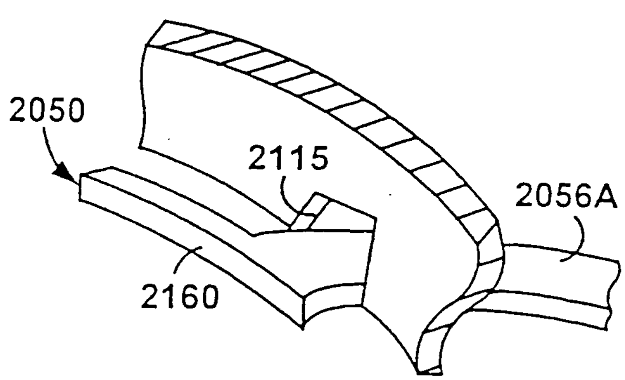


FIG. 22

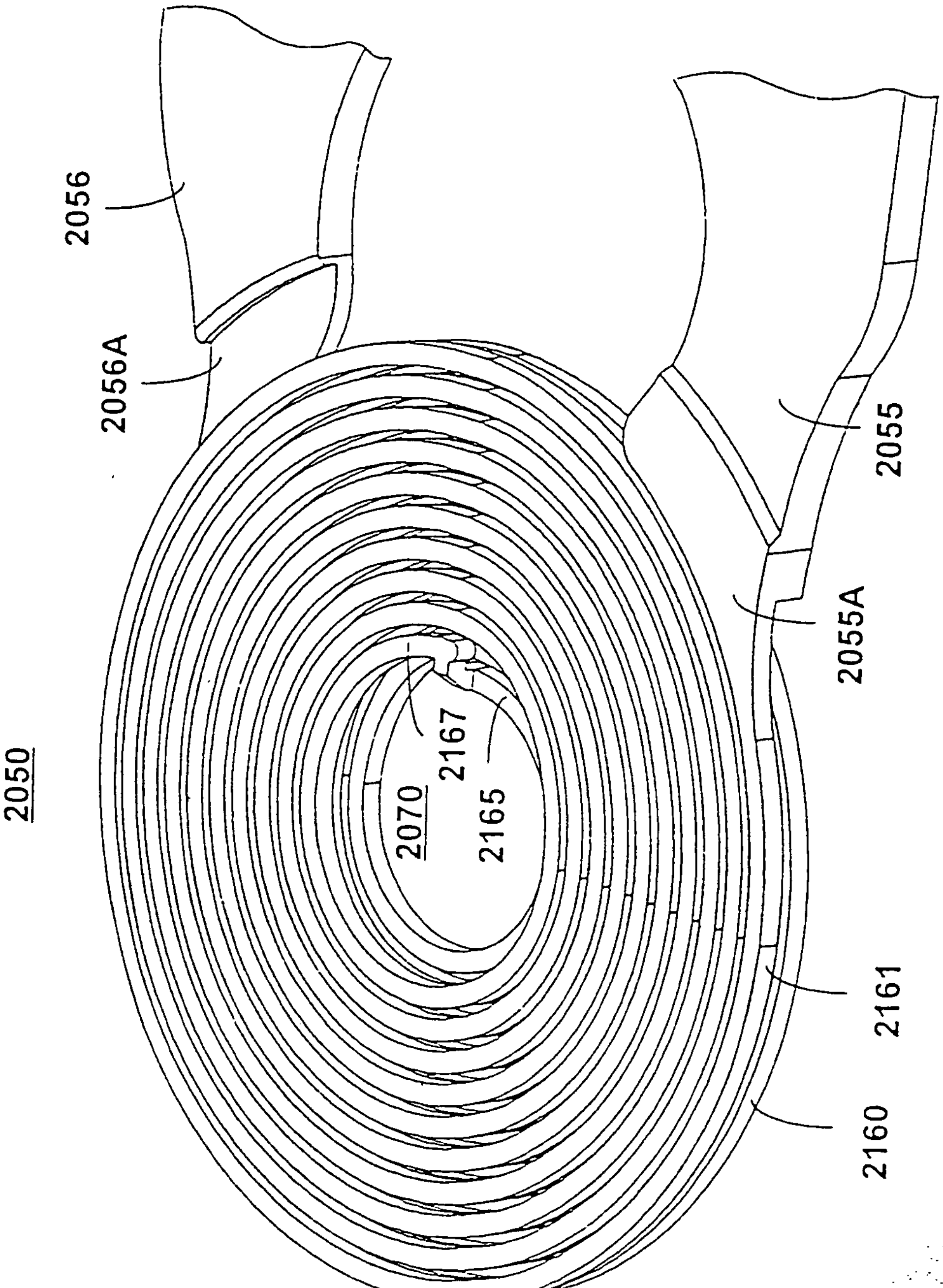


FIG. 23

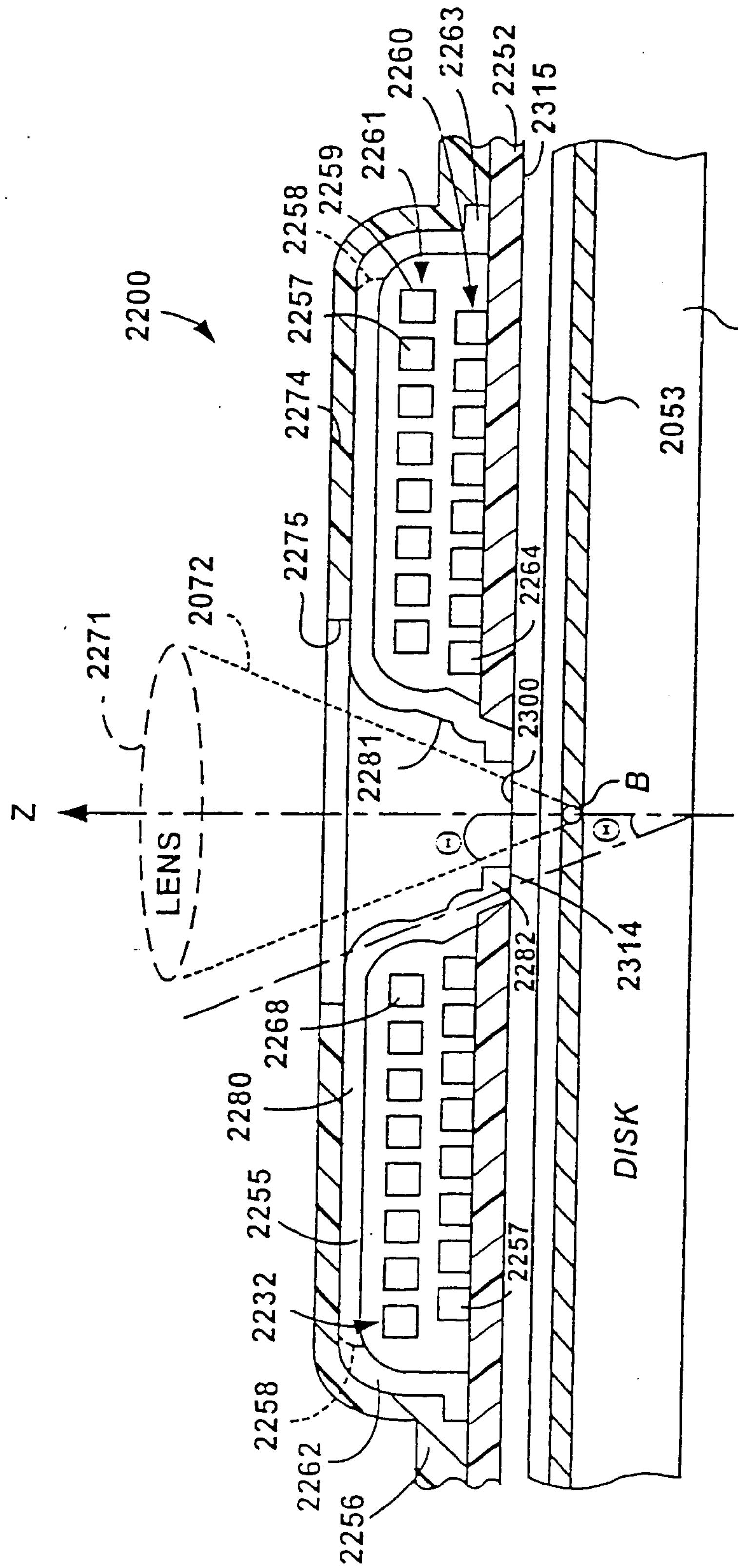

2200
2260
2263
2252
2315
2261
2259
2258
2257
2274
2275
2072
2271
2014
2053
2264
2300
2281
B
Z
LENS
2314
2282
2268
2280
DISK
2255
2257
2232
2258
2262
2256

FIG. 25

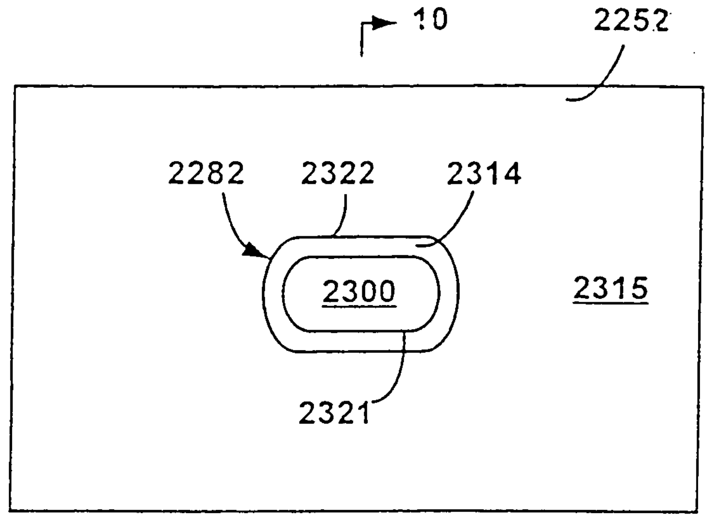


FIG. 25A

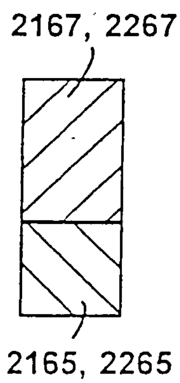


FIG. 27

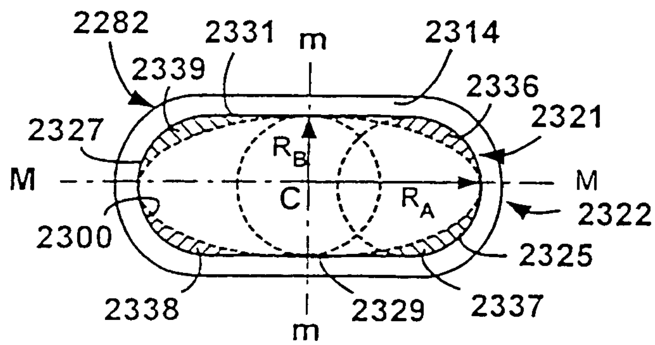


FIG. 28

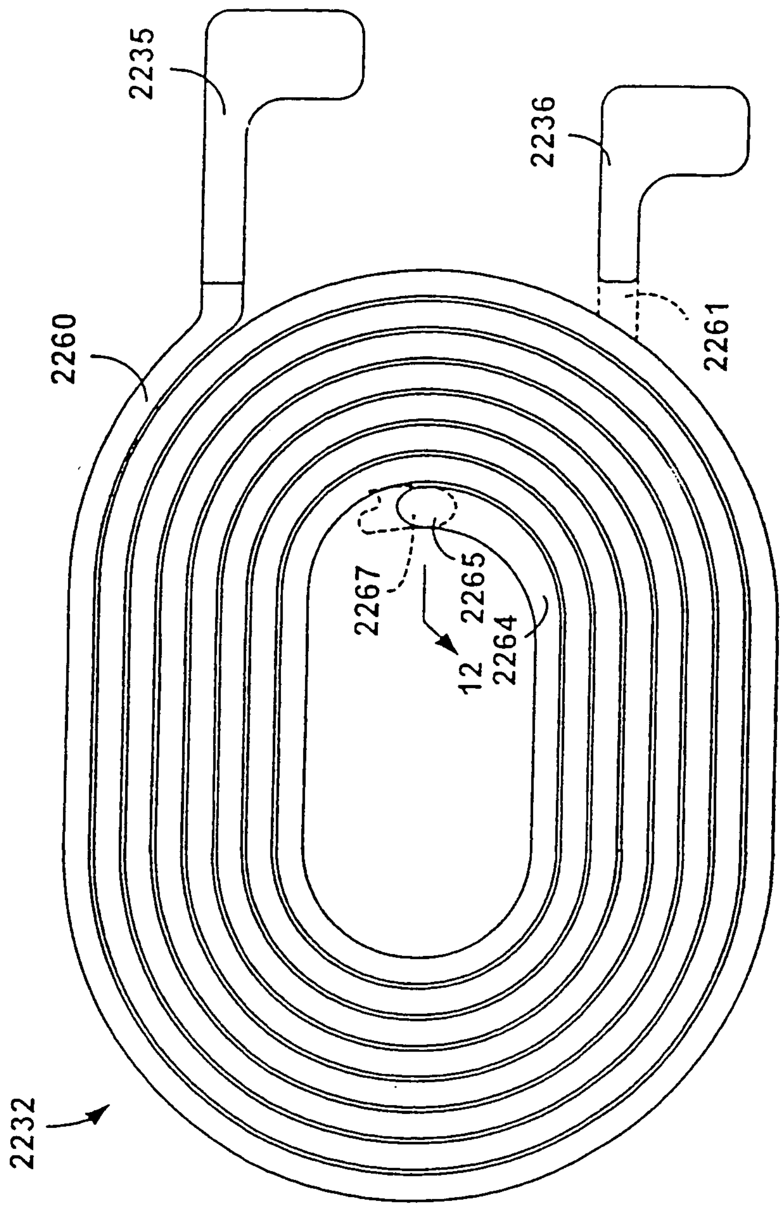


FIG. 26

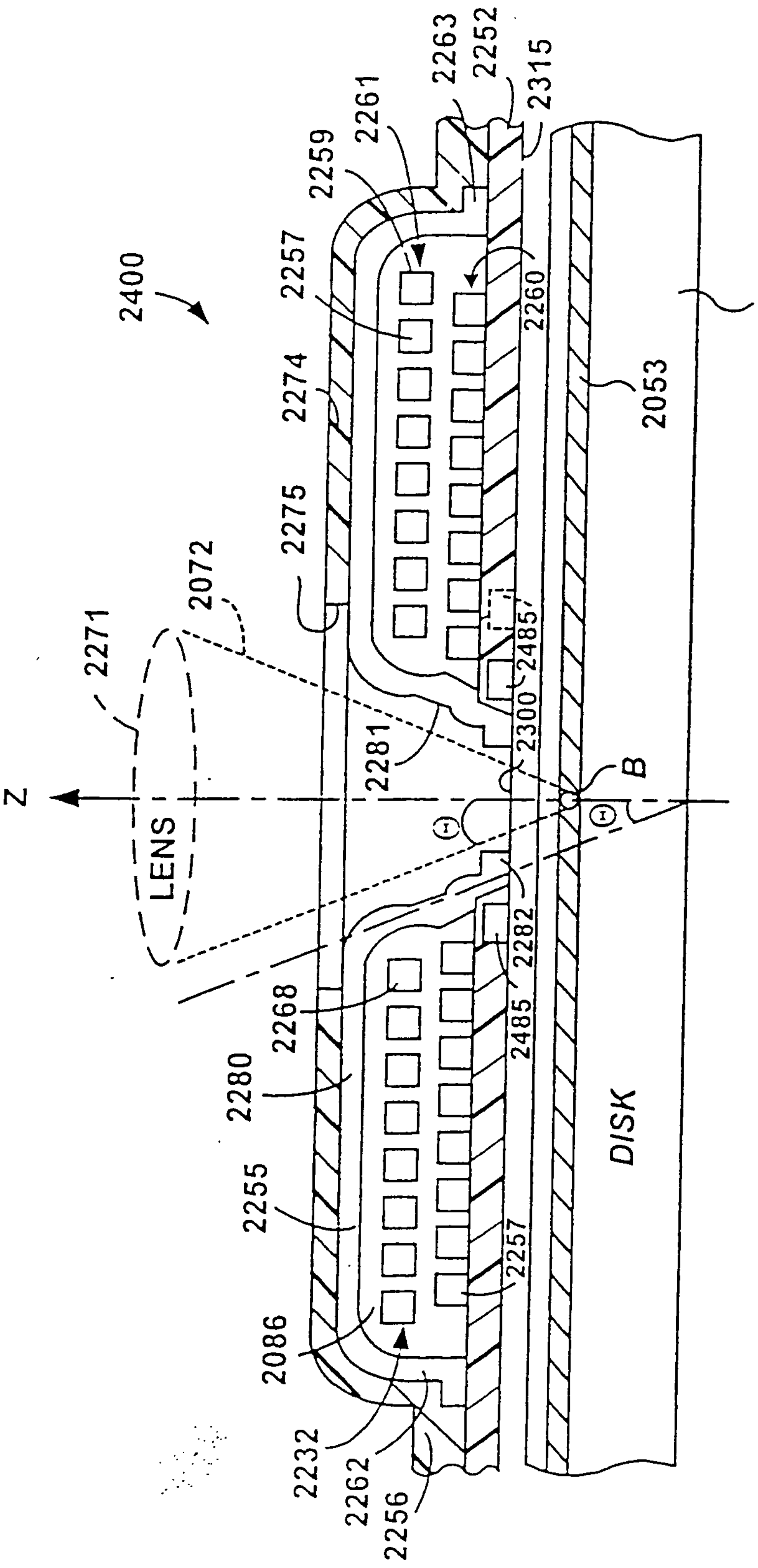

2400
2263
2252
2315
2261
2259
2257
2260
2014
2053
2274
2275
2072
2271
2485
2300
2281
B
Z
LENS
2282
2485
2268
2280
DISK
2255
2257
2086
2232
2262
2256

FIG. 29

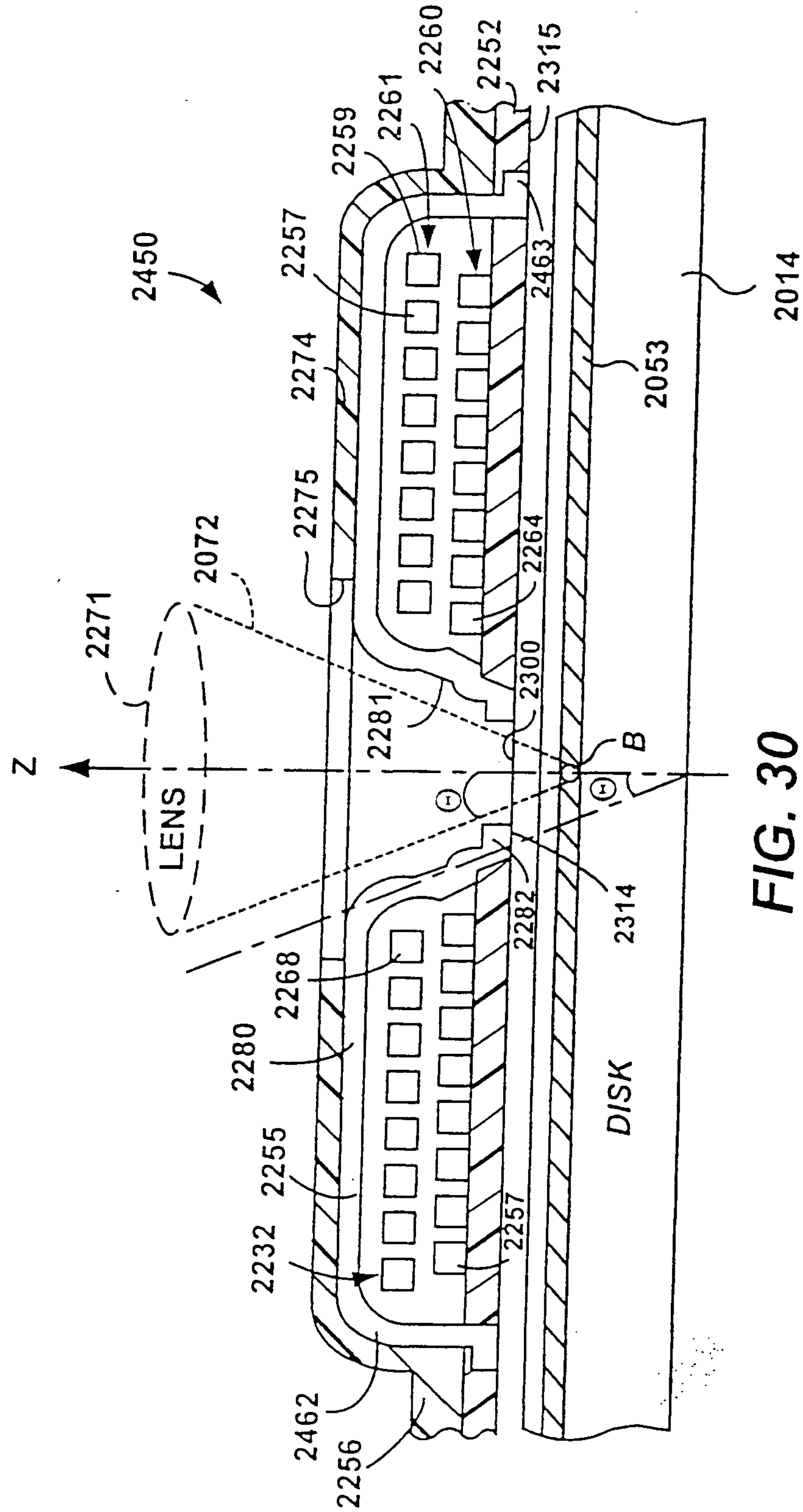

2450
2257
2259
2261
2260
2252
2315
2463
2014
2053
2274
2275
2264
2072
2271
2300
2281
Z
B
LENS
2314
2282
2268
2280
DISK
2255
2257
2232
2462
2256

FIG. 30

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US98/06651

A. CLASSIFICATION OF SUBJECT MATTER

IPC(6) : G11B 11/00
US CL : 369/13; 360/114
According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

U.S. : 369/13, 14, 110; 360/102, 103, 59, 114

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

APS

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 5,295,122 A (MURAKAMI et al) 15 March 1994 figures 3, 6 and column 5, lines 38-53.	1-39
X	US 4,890,178 A (ICHIHARA) 26 December 1989 figure 12, yoke 7, coil 5.	1-39

☐ Further documents are listed in the continuation of Box C. ☐ See patent family annex.

* Special categories of cited documents:

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier document published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

Date of the actual completion of the international search 29 JUNE 1998	Date of mailing of the international search report 12 AUG 1998
Name and mailing address of the ISA/US Commissioner of Patents and Trademarks Box PCT Washington, D.C. 20231 Facsimile No. (703) 305-3230	Authorized officer TAN XUAN DINH Telephone No. (703) 308-4859